Top-down and Bottom-up influences on ACC activation:

Evaluation of a proposed model of the feedback-related negativity

By

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Abstract

The Feedback-Related Negativity (FRN) is thought to reflect the dopaminergic prediction error signal from the subcortical areas to the ACC (i.e., a bottom-up signal). Two studies were conducted in order to test a new model of FRN generation, which includes direct modulating influences of medial PFC (i.e., top-down signals) on the ACC at the time of the FRN. Study 1 examined the effects of one's sense of control (top-down) and of informative cues (bottom-up) on the FRN measures. In Study 2, sense of control and instruction-based (top-down) and probability-based expectations (bottom-up) were manipulated to test the proposed model. The results suggest that any influences of medial PFC on the activity of the ACC that occur in the context of incentive tasks are not direct. The FRN was shown to be sensitive to salient stimulus characteristics. The results of this dissertation partially support the reinforcement learning theory, in that the FRN is a marker for prediction error signal from subcortical areas. However, the pattern of results outlined here suggests that prediction errors are based on salient stimulus characteristics and are not reward specific.

A second goal of this dissertation was to examine whether ACC activity, measured through the FRN, is altered in individuals at-risk for problem-gambling behaviour (PG). Individuals in this group were more sensitive to the valence of the outcome in a gambling task compared to not at-risk individuals, suggesting that gambling contexts increase the sensitivity of the reward system to valence of the outcome in individuals at risk for PG. Furthermore, at-risk participants showed an increased sensitivity to reward characteristics and a decreased response to loss outcomes. This contrasts with those not at risk whose FRNs were sensitive to losses. As the results did

not replicate previous research showing attenuated FRNs in pathological gamblers, it is likely that the size and time of the FRN does not change gradually with increasing risk of maladaptive behaviour. Instead, changes in ACC activity reflected by the FRN in general can be observed only after behaviour becomes clinically maladaptive or through comparison between different types of gain/loss outcomes.

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One of the hallmarks of adaptive behaviour is ability to monitor the environment and adjust one's actions in response to any changes that occur. In humans, such behaviour can be described in terms of setting goals and self-regulating to achieve these goals. Successful adaptation to change relies on a number of neural networks which support basic processes (e.g., sensation and perception of the environment), keep track of the individual's goal (e.g., complete a draft of a dissertation), allow the inhibition of interfering desires (e.g., watching TV instead of writing) and re-adjustment of expectations and goals when the environment changes (e.g., getting sick for two days and not being able to write). Although, humans often have more complex goals compared to other organisms (e.g., completing a paper versus obtaining a food pellet), the underlying neurocircuits involved in goal-directed behaviour are very similar. One such circuit is the mesocorticolimbic dopaminergic pathway, which is often referred to as the reward pathway of the brain.

Reward-related neurocircuitry

This pathway originates in the dopaminergic cells in the ventral tegmental area, projects to the nucleus accumbens (nAcb) and then to the limbic system (see Tobler & Kobayashi, 2009 for review), allowing for coding of objective reward value and motivational value of the stimulus, respectively. Neurons in the ventral tegmental area also project to the prefrontal cortex (Bjorklund & Dunnett, 2007). The prefrontal cortex can be further subdivided into medial frontal (including the orbitofrontal cortex) and dorsolateral prefrontal cortex. The medial frontal cortex has been shown to be sensitive

to the subjective value of the stimulus (Potts, Martin, Burton & Montague, 2006; Kable & Glimcher, 2007). The dorsolateral prefrontal cortex is not directly involved in the processing of reward value but is responsible for executive functions such as integration of sensory information and working memory (Goldman-Rakic, 1995), which are used to hold current goal information.

Additionally, dopaminergic neurons from the ventral tegmental area project to the cingulate cortex (Bjorklund & Dunnett, 2007), which receives a number of inputs from the limbic system and the medial prefrontal cortex (mPFC; Vogt & Pandya, 1987; Devinsky et al., 1995) and acts as an interface between the subcortical and cortical structures. More specifically, the anterior cingulate cortex (ACC) receives projections from the ventral tegmental area (Tobler, & Kobayashi, 2009). Additionally, the orbitofrontal cortex (Brodamnn's areas 11, 12) as well as the dorsolateral prefrontal cortex (Brodmann's areas 9 and 46) have projections to the ACC (Vogt & Pandya, 1987) suggesting that the ACC integrates information regarding subjective reward value and current goals of the organism. The ACC has also been shown to have efferent connections to the prefrontal cortex, which then projects back to the nAcb (from Brodmann areas 24 and 25; Devinsky et al., 1995), thus, forming a feedback loop. In summary, coding of reward value of a stimulus is divided between subcortical areas for the objective value and medial frontal corticies for the subjective value. This information is then compared and integrated with the current goals (received from the dorsolateral prefrontal cortex) and projected back with updated information regarding achievement or failure of the current goal. Both dorsolateral prefrontal cortex and the ACC have been shown to contribute to execution of willed actions such that the ACC plays a role in

response selection and is central to initiation of responses (for a review see Devinsky et al., 1995). Consistent with these findings, the ACC has been shown to be sensitive to performance monitoring such that its activity changes in response to errors committed or negative outcomes in the environment (Miltner, Braun, & Coles, 1997; Carter, Braver, Barch, Botvinick, Noll, & Cohen, 1998; Botvinick, Cohen, & Carter, 2004). An in-depth investigation of pathways between the ACC and dorsolateral prefrontal cortex demonstrated that the dorsolateral prefrontal cortex contains mostly excitatory projections into the ACC, whereas the ACC utilizes more inhibitory projections (Medalla & Barbas, 2009). The authors suggest that these projections are used to supress task-irrelevant stimuli, increasing the salience of goal-relevant information. Thus, the ACC monitors incoming information and suppresses activity after unwanted outcomes. Favourable outcomes lead to increased overall activity due to the lack of inhibition coming from the ACC. In this fashion, the information regarding the outcomes of goal-directed behaviour is coded in the system and is updated after each action. Consistent with this proposal, the ACC has also been shown to be the generator for a number of event-related potential components associated with performance monitoring and error detection (for a review see Gehring, Lui, Orr & Carp, 2012), which can be conceptualized as markers for unfavourable outcomes of one's actions. Based on the extensive evaluation of research utilizing these components, Holroyd and Coles (2002) proposed that the ACC is responsible for "generic" error-processing and the observed activity at the scalp occurs in response to changes in dopamine levels in the ACC.

More specifically, the ACC has been shown to produce a negative deflection at the scalp that can be observed when participants are aware of making an error on a

speeded task, referred to as the error-related negativity (ERN; Dehaene, Posner, & Tucker, 1994). The ERN is usually observed in Flanker or Go/NoGo tasks, where participants do not need to rely on external feedback to know they have made an error, and appears around the time of the response (i.e., peaking shortly following the initiation of a button press) indicating that it is a response to recognition that they are about to make an error and it's too late to prevent it. Holroyd and Coles (2002) proposed that this component is a marker for reinforcement learning processes utilized by the nervous system for evaluation of one's actions.

Prior to any event, a prediction is made by the system regarding the outcome of the event. The obtained outcome (e.g., an error following a button press) is then evaluated relative to the prediction. If the outcome is worse or better than expected a "prediction error signal" can be observed in the system. In terms of neurobiological mechanisms, the predictions regarding the outcomes are coded in the basal ganglia by the activity of dopaminergic neurons. Basal ganglia is a relative large structure in the brain containing the ventral tegmental area, ventral striatum and nAcb (Tobler, & Kobayashi, 2009). In case of a prediction error (e.g., omitted reward) dopaminergic activity in these areas will drop at the time of the expected reward (Shultz, 1997). Similarly, dopaminergic activity increases in the case of positive prediction error (i.e., attainment of a reward). These signals are then conveyed to the ACC and higher cortical areas, leading to learning and adaptation of behaviour, and can be observed at the scalp as components generated by the ACC (Holroyd & Coles, 2002). Prediction error signals can be initiated by the external feedback from the environment (e.g., low grade on a paper) or internal

monitoring (e.g., accidentally swearing in a meeting). In both situations, the individual is aware that a negative, and unexpected, event has occurred.

Apart from the ERN, the ACC has also been shown to produce a negative-going ERP component in response to external feedback (see Hauser et al., 2014). This negative deflection occurs about 200ms after the onset of the feedback stimulus, and is often referred to as the feedback-related negativity (FRN) or, due to a similarity in the topography with the ERN, feedback ERN (fERN). This component is often observed on tasks that require external feedback in order to evaluate performance, such as in gambling or learning tasks. In such tasks, the evaluation and generation of the prediction error can be observed at a known specific time point as individuals are unable to evaluate their performance until feedback is presented. The goal of this dissertation is to propose and test a more comprehensive model of generation and modulation of the prediction errors, as marked by the FRN. In order to understand the need for an updated model, we need to consider the development of theories and progression of research examining the sensitivity of the FRN to various stimulus and task characteristics.

Feedback-Related Negativity

The FRN was first reported as an independent component in 1997 by Miltner, Braun and Coles. Individuals participating in the study were asked to look at a blank screen, following a cue, and press a response key when they thought one second has elapsed (i.e., a time estimation task). In this task, participants do not know if they've made an error (i.e., under- or over-estimated the correct time) until feedback is presented. Researchers presented feedback in three different modalities and showed that, regardless of modality of presentation, the FRN was larger in amplitude following negative

feedback (incorrect) compared to positive (correct). Additionally, the dipole analysis modeled the ACC as a generator for the FRN. Thus, it seemed that the FRN was a marker for negative outcomes or incorrect performance.

In 2002, Gehring and Willoughby observed a similar component after presentation of feedback in a gambling task. Participants were asked to choose between two cards, either one of which could be a win or a loss. Again, individuals had no way of evaluating their choice until the outcome (i.e., + or –) was revealed. As in the time estimation task, negative feedback (i.e., loss) elicited larger FRN amplitude, when compared to positive feedback (i.e., win). At the time of the outcome, the valence of the non-chosen card was also revealed. The outcomes were divided into four types: win-correct (i.e., choosing a winning card when the alternative was a loss), win-error (i.e., choosing a winning card when alternative was a win of a larger magnitude), loss-error and loss-correct. Interestingly, the FRN was not sensitive to the distinction between correct and incorrect choice (i.e., loss-correct and loss-error), but varied only in response to the valence of the outcome. As in the previous study, the ACC was also modeled to be the generator for the FRN, suggesting that it is not sensitive to degree of failure of task goals rather activity of the ACC is modulated by the objective valence of the outcome. Using the terms of reinforcement learning theory, unfavourable outcomes generate a larger prediction error, which is then projected to the ACC and can be observed as larger FRN amplitude. The authors did not directly examine the effects of magnitude on the sensitivity of the FRN, so it was unclear if this 'prediction error signal' is also sensitive to other objective stimulus characteristics.

Since 2002, there have been a number of studies examining the characteristics of the feedback stimulus that affect the FRN, in an attempt to understand the intricacies of its functional significance, and in turn, characteristics that modulate the magnitude of prediction errors. Yeung and Sanfey (2004) have used a gambling paradigm similar to Gehring and Willoughby (2002) to evaluate the sensitivity of the FRN to the magnitude of the outcome (e.g., large win vs. small win). In this study, the FRN did not appear to differentiate between the magnitudes of the stimuli but differentiated positive and negative outcomes in the expected direction (i.e., losses elicited a larger FRN compared to wins). They concluded that the FRN, and in turn the ACC, was sensitive only to the positive versus negative distinction of the outcomes (i.e., attainment of/failure to obtain a reward). This finding has been replicated a number of times using similar tasks (Toyomaki & Murohashi, 2005; Goyer, Woldorff, & Huettel, 2008; Kamarajan, et al., 2009) and suggests that the FRN is a marker for the occurrence of positive and negative prediction errors, regardless of the magnitude of the obtained or omitted reward.

Hajcak et al. also investigated the sensitivity of the FRN to the magnitude of the outcome and reached similar conclusions (Hajcak, Moser, Holroyd & Simons, 2006). The FRN was not sensitive to various magnitudes of the outcomes but differentiated only between the valence of the stimulus (i.e., win and loss) suggesting that the dopaminergic signal codes for objective rewards (wins) and punishments (losses), rather than differentiating those based on magnitude of the outcome. To ensure that the FRN was sensitive to the outcomes in binary fashion (good vs. bad), the authors conducted a second experiment with the same task and included a “nothing gained or lost” feedback condition. These outcomes elicited FRNs of similar magnitude to the loss outcomes,

suggesting that the ACC was engaging in the binary evaluation of the outcomes coding only for achieving or failing to achieve task goals rather than objective magnitude of the outcome.

These results were partially consistent with an earlier paper where similar outcomes were used (Holroyd, Larsen, & Cohen, 2004). In this study, participants were asked to choose between three 'balloons' during three types of conditions across two experiments. In the 'even' conditions, the balloons could lead to a win of 10 cents, a loss of 10 cents, or no change (i.e., zero outcomes; Experiment 1). The second experiment contained a 'win' condition, where the outcomes were either 'zero' (i.e., worst option) or a win of 2.5 cents (middle option) or a win of 5 cents (best option). The 'loss' condition had the same options but in the reverse order (i.e., 'zero' was the best and loss of 5 cents was the worst outcomes). In the first experiment, the FRN was larger for loss and zero compared to win outcomes, suggesting that the system is sensitive to the reward/no-reward dichotomy. However, in the second experiment, FRN elicited by the 'zero' outcomes differed depending on the condition (i.e., win or lose), such that larger FRN was observed when 'zero' was the worst possible outcome (i.e., win condition) compared to the best possible outcome (i.e., lose condition). The authors interpreted these results as evidence for the context-dependent sensitivity of the FRN to the valence of the outcomes. Thus, even in the absence of objective reward, a prediction error signal is still generated based on the subjective value of the outcome. In other words, FRN reflects a prediction error signal that is based on both, the stimulus characteristics and the task goals (i.e., context of the stimulus), and the combination of these factors is reflected in the subjective value of the stimulus.

Sensitivity of the FRN to the subjective value of the outcome was further investigated using a slot-machine task (Donkers, Nieuwenhuis & van Boxtel, 2005). Participants were told that on the trials where the three stimuli on the screen are identical (e.g., xxx) they will either gain or lose money, depending on the condition. The stimuli were presented one at a time and on some trials all three stimuli were different (e.g., xyz) while on others the first two were the same (e.g., xxy). The FRN elicited by the presentation of the third stimulus was compared across four outcome conditions: gain, averted gain, averted loss and loss. The authors found that the FRN to the 3rd stimulus was not sensitive to the valence of the outcome per se but rather appeared to differentiate between three 'same' and three 'different' stimuli, i.e., averted versus not-averted conditions. More specifically, FRN was largest in amplitude when the preceding two stimuli were the same but the third one differed (e.g., xxy). Although this type of stimulus led to averted wins or losses, depending on the condition, the FRN was not sensitive to this distinction. In a follow up study, the authors examined the possibility that the FRN was influenced by the frequency-sensitive N2, often seen in oddball tasks (Donkers & van Boxtel, 2005). Participants were asked to engage in a similar task, with manipulated frequency of gains/losses and, thus, different probabilities of avoiding each one. In order to eliminate any possible effects of the frequency-sensitive N2 at the time of the outcome presentation, difference waves between wins and losses were computed for each level of probability. It is important to note that the presented stimuli for averted gains and losses were objectively the same (i.e., xxy). The meaning of the outcome was determined by the condition of the task, or in other words, task instructions. The authors found that averted gains elicited larger FRNs compared to averted losses. This finding is

consistent with previous research showing that the FRN is sensitive to the valence of the outcome in a binary fashion (i.e., positive vs. negative). The reinforcement learning theory suggests that omitted rewards (i.e., averted gains) produced a larger prediction error than omitted punishments (i.e., averted losses), and this difference is then reflected in the size of the FRN. FRN following wins (i.e., gains) was also modulated by the probability of the outcome: most unexpected outcomes elicited the largest FRN. Thus, stimulus subjective valence and expectedness (both of which are necessary to formulate a prediction) appear to modulate the response of the ACC to presented outcomes.

One possible confound, as highlighted by Donkers and van Boxtel (2005), that arises when examining the relationship between stimulus expectancy and the FRN is the frequency of the stimuli presented. Often expectations are manipulated by varying probability of an outcome, which necessitates unequal frequency of outcomes with different valence. A frequency-sensitive N2 component, which is a negative deflection in the waveform, was shown to be larger for infrequent events compared to frequent ones (for a review of N2/ERN/FRN see Gehring et al., 2012) and occur at a time similar to the FRN (suggesting the FRN is an N2 in a specific context). Thus, it is possible that effects of expectations on the FRN can be confounded with the effects of stimulus frequency on the N2. For example, Cohen, Elger and Ranganath (2007) examined the effects of expectations on the FRN by presenting participants with a gambling paradigm (choose between two cards), where probability of the reward (25%, 50% or 75% reward) was varied between blocks. This probability manipulation was unbeknownst to the participants, and only had an effect on the FRN elicited by wins, such that FRN amplitude was less negative (or more positive) as wins became more unexpected (i.e.,

25%>50%>75%). These results are similar to those observed by Donkers et al. (2005) such that only FRN following wins was affected by probability manipulation. It should be noted that Cohen et al. (2007) did not control for the possible effects of frequency-sensitivity of the N2 as probability was manipulated by changing the frequency of the outcomes. However the consistency of these results with those presented by Donkers et al. (2005), who did control for frequency N2 effects at the time of the FRN, suggests that any effects of the frequency-sensitivity of the N2 at the time of the FRN do not significantly impact on the FRN amplitude. Furthermore, FRNs observed to near-wins in another study using a slot machine task were larger than those elicited by the wins and smaller than those observed after complete losses (Luo, Wang, & Qu, 2011). In this slot-machine study, all of the outcomes had equal frequencies (i.e., no frequency effects), thus, supporting the hypothesis that frequency-sensitivity of the N2 has minimal impact on the FRN. Finally, similar to Donkers et al. (2005), probability effects observed by the Cohen and colleagues (2007) were present only on the gain trials. Thus, it is possible that positive outcomes are treated differently by the system compared to negatively valenced stimuli.

Effects of Expectation of Outcome on the FRN.

The influence of expectations on the FRN sensitivity was further examined by Bellebaum and Daum (2008) in a learning paradigm. Participants' progress could be measured while they were learning that the stimuli had different probabilities of winning. Thus, in the first half of the FRN elicited by the presentation of the outcome was largest in amplitude for unexpected negative outcomes compared to expected or positive outcomes. Unlike in the previously described studies (Donkers et al., 2005; Cohen et al.,

2007), in this task, when participants are still learning the rules, no expectations were present. In the second half of the task, once the rules were learned, participants' expectations could be predicted. The FRN following wins did not differentiate between outcomes of different probabilities. Kobza and colleagues (2011) also investigated the sensitivity of the FRN to the probability of the outcome in a learning paradigm. The FRN was found to differentiate between wins and losses only in low-probability conditions and only in those participants that learned the rules of the task. There were no interactions with probability in non-learners. Thus, although the FRN seems to be sensitive to the frequency/probability of the outcome, it is still unclear why these effects are observed only for one type of outcome valence (i.e., either reward or non-reward). Nevertheless, both studies illustrate that learning is necessary for these effects to occur, suggesting that probability of the outcome affects participant's expectations, which then modulate the FRN.

The necessity of expectation development for FRN modulation was further demonstrated by Bismark et al. (2013) by examining the effects of the time of the feedback presentation and the active/passive involvement of participants in the task. In one of the three versions of a gambling paradigm, participants chose a 'balloon' and were shown a white square around it, which allowed time for expectations to develop (self-choice). In the other versions of the task, participants were shown the same screen but the choice was made by a computer. They were then shown either the same white square (observer-delay) or immediately given feedback (observer-immediate). Expected FRN-valence effects (i.e., larger FRN after losses) were observed in the self-choice condition and observer-delay conditions. There were no significant FRN-valence effects in the

observer-immediate condition. The authors concluded that time to develop expectations is necessary for any FRN effects, suggesting that expectations are the driving force behind the sensitivy of the FRN to the valence of the outcome. This interpretation is consistent with the reinforcement learning theory, as expectations are necessary for formation of prediction errors, which in turn are necessary for modulation of the FRN. Thus, it appears that the ACC seems to evaluate outcomes with respect to one's expectations rather than subjective or objective valence of the stimulus.

Importance of Expectations over Stimulus Value.

This distinction is supported by the results of Gu, Wu, Jiang and Luo (2011), who used a classical two-choice gambling paradigm to examine the sensitivity of the FRN to the alternative outcomes. As in other gambling tasks, participants were asked to guess which of the two presented cards was a winning card. Unlike in other studies, the valence of the alternative card (i.e., not chosen card) was presented first, followed by the valence of the chosen card. The FRN observed after the outcome on the chosen card showed the expected pattern, such that losses elicited larger FRN compared to wins. The FRN was also sensitive to the distinction between valence of the alternative card, but not in the expected direction (i.e., larger FRN after losses than wins). Alternative outcomes of positive valence (i.e., wins) elicited larger FRN when compared to negatively valenced (i.e., loss) alternative outcomes. This finding further illustrates the lack of sensitivity of the FRN to the objective valence of the stimulus. The authors also note that although the valence of the alternative and chosen cards were independent, participants might have assumed that positive alternative card decreases their chances of winning on the chosen card. Consistent with this assumption, the largest FRN was observed when losses on the

chosen card were presented after a negatively valenced alternative card (i.e., unexpected losses). Thus, participants formed expectations based on the alternative outcome and the size of FRN reflected the degree of violation of these expectations (i.e., a prediction error).

Expectations of Value and the FRN.

The effects of expected value of the outcome on the FRN were also investigated by San Martin and colleagues (2010). The authors presented participants with four possible choices, which were coded based on their magnitude and probability of winning, resulting in four stimuli: small size/low probability, small size/high probability, large size/low probability and large size/high probability. These combinations of stimuli allowed the authors to have comparisons between stimuli of different expected value. Participants had to guess which response button would lead to the best choice and were aware of both the size and probability of the outcome. Losses produced a larger FRN in general and were not differentiated based on probability or magnitude, consistent with previous research (Donkers et al., 2005; Cohen et al., 2007). However, win outcomes elicited significantly larger FRN on the trials with low expected value (i.e., low probability/low magnitude outcomes). The authors concluded that both of these characteristics affect the expected value of the reward, which is reflected in the ACC activity. As in previous research (Donkers et al., 2005; Cohen et al., 2007; Kobza et al., 2011), the pattern of FRN sensitivity for positive and negative outcomes was not the same. Taken together the results of these studies suggest that stimulus characteristics for rewards and non-rewards (e.g., magnitude, probability) are processed separately by the reward network.

In fact, support for this was shown by Holroyd, Pakzad-Vaezi and Krigolson (2008), who demonstrated that rewards elicit a positive deflection at the time of the FRN (i.e., reward positivity).[1] Holroyd et al. (2008) have proposed that valence effects observed in the FRN are driven by a reward positivity occurring after correct/positive feedback, which modulates the negative deflection (i.e., N2) occurring in response to task-relevant events. Thus, negative feedback does not elicit larger N2 response compared to positive feedback, but rather positive feedback is followed by a positivity that decreases the N2 response. This positivity was shown to occur in response to events of positive valence (Holroyd et al., 2008), unexpected rewards (Holroyd, Krigolson, & Lee, 2011) and to be sensitive to the magnitude of the reward (Kreussel et al., 2012). Lole et al. (2013) investigated this distinction further by conducting a spatial principal component analysis (PCA) on the waveforms obtained during an electronic gaming machine task. Participants were asked to bet either a large or a small amount of money on each trial and won when all four presented pictures were exactly the same. The outcomes were separated into three bins: wins, near misses (i.e., three out of four pictures were the same) and losses. Spatial PCA analysis revealed two waveforms at the time of the FRN: a negative deflection after loss outcomes and a positive deflection after wins. This positive deflection was also sensitive to the magnitude of the outcome, such that larger reward magnitudes elicited a greater positivity compared to smaller ones. Thus, the FRN seems to be a combination of two separate events. A negativity that occurs following non-rewards and punishments, that is further modulated by unexpectedness of an event, and a positivity that occurs after reward and is also modulated by the

[1] Normally, of course, it is not possible to differentiate positive deflections due to reward from negative deflections due to losses/punishment when comparing the two types of outcomes.

expectedness (Holroyd et al., 2011) of the event as well as its magnitude (Lole et al., 2013).

These findings are consistent with the reinforcement learning theory proposed by Holroyd and Coles (2002) such that rewards and punishments lead to opposing activity of the ACC, which is reflected as positivity (after rewards) and negativity (after punishments) at the time of the FRN. After a review of the literature examining the ERN and the FRN, they suggest that these components reflect the dopaminergic activity in the subcortical structures (e.g., nAcb) which is projected to the ACC. Combined with the works of Shultz (2007), who examined the responses of the nAcb to rewards and punishments in rats, this theory would suggest that FRN reflects a prediction error that is coded in the nAcb. These neurons respond to rewards and omitted rewards by generating a prediction error signal for each type of the outcome, such that reward leads to an increase in dopamine levels, which further increase if the reward was unexpected. Losses or omitted reward, on the other hand, lead to a drop in dopamine levels, which is even greater when these events are unexpected (see Figure 1.0).

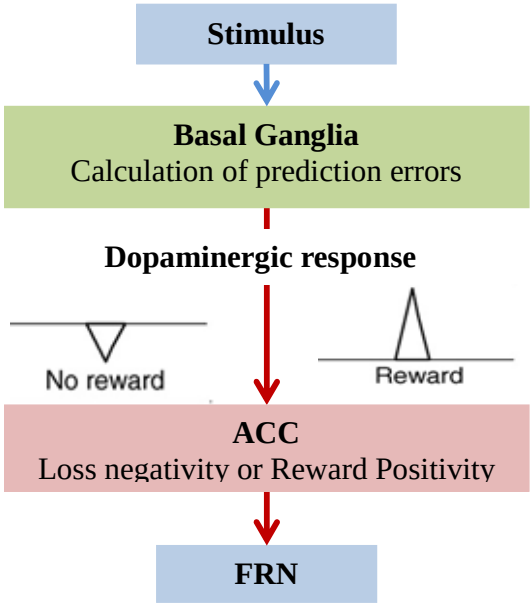

Figure 1.0. Schematic representation of the reinforcement learning theory of FRN generation.

The Role of Top-Down Factors

The review of the literature suggests that the FRN is a marker of prediction errors which are coded in the subcortical areas (i.e., basal ganglia) and projected to the ACC. Under certain task conditions, these prediction errors can be dissociated and shown to have differential activation for rewards and omitted rewards, which can be further modulated by salient stimulus characteristics (e.g., magnitude). These conclusions are in line with the reinforcement learning theory, which specifies that a prediction error signal is coded in the subcortical areas and projected to the ACC. Previous research has also shown that objectively identical stimuli can elicit differential ACC activation depending on the instructions given (Holroyd et al., 2004). There was no competition between the identical stimuli as the valence of these stimuli was blocked within condition, ensuring that the valence marker for the stimulus can be easily coded in the subcortical areas (i.e., information was simple and did not require a choice between cognitive interpretations).

However, previous research has also shown that more complex constructs such as one's sense of responsibility over the outcome (Li et al., 2010), trustworthiness of the partner in the game (Long, Jiang, & Zhou, 2012), personality (Santesso & Segalowitz, 2009; Segalowitz & Dywan, 2009; Santesso, Dzyundzyak, & Segalowitz, 2011) and cognitive reappraisal (Yang, Gu, Tang, & Luo, 2013) modulate FRN amplitude. Such complex cognitive constructs rely on the activation of larger cortical networks in order to integrate the information successfully and adjust one's interactions and response to the stimuli in the environment. Thus, it is likely that these networks heavily rely on the cortical areas, and more specifically the prefrontal cortex, given its sensitivity to rewards (for review O'Doherty & Dolan, 2006). Given the reciprocal connections of the ACC with the prefrontal cortex (Vogt & Pandya, 1987; Devinsky et al., 1995), it is then plausible to assume that goals, subjective value and expectations are integrated in higher cortical areas and then relayed to the ACC via top-down projections. This information is then used to modulate one's response to the outcomes in the environment by affecting the interpretation or salience of the stimulus. This model was proposed in order to explain the results of my Master's thesis, where unexpected FRN patterns were observed.

Master's thesis data

One of the goals of my Master's study was to examine if FRN is sensitive to valence and magnitude of the stimulus in various contexts. One way of changing the salience of the stimulus through instructions is by giving participants a higher level of control over the outcome. Most studies investigating FRN sensitivity to stimulus characteristics use variations of gambling paradigms, where participants are guessing which choice to make in order to win. In order to address the research question, the FRN

was examined in three task contexts: to the outcomes in a standard two-card gambling task; to cues that give the subject valence information (i.e., potential win or loss) concerning the current trial in a speeded-response task; and to the outcome feedback in the speeded response task. In the gambling task, participants had to choose between two cards of different magnitude. Once the choice was made, the outcome (+ or –) was revealed. In the Monetary Incentive Delay (MID) task providing the latter of the two contexts, participants were first presented with a cue labelling the trial as either a win or a loss of small or large magnitude. In order to win, participants had to press a response button while the target stimulus was one the screen. There were four types of outcomes in this task, depending on the preceding cue: win, missing a win, avoiding a loss, loss. We compared the FRNs elicited by the outcomes in both tasks as well as the FRN-like component observed after the cue (referred to as cue-FRN from now on).

The Cue-FRN was sensitive to the valence of the cues, such that cues signifying potential losses elicited a larger cue-FRN amplitude when compared to potential win cues. This finding is consistent with the reinforcement learning theory, if we assume that prediction errors are generated any time a stimulus has valence (i.e., regardless of whether it is an outcome of an action). On the other hand, this activity can be in response to the salience of the stimulus – potential losses are more arousing and signify the potential need for more resources in the upcoming trial. In fact, Talmi and colleagues (2013) argue that FRN is a reflection of salience of prediction errors rather than the rewarding nature of the error. However, the results of their study cannot be used to differentiate between these two possibilities.

More interestingly, the outcomes in the two tasks elicited different patterns of the FRN. In both tasks, losses elicited an FRN of equal size that was larger in amplitude than that observed after wins on the gambling task. Surprisingly, wins in the MID task were followed by an FRN of larger amplitude compared to losses on either task (see Figure 1.1).

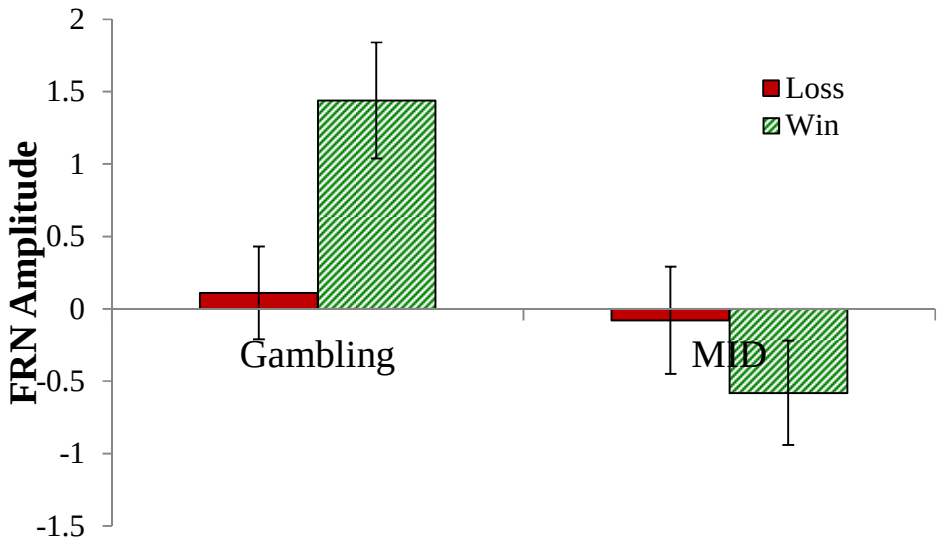

Figure 1.1. Average FRN amplitude elicited by the outcomes in the gambling and MID tasks in Dzyundzyak (2010).

As discussed earlier, frequency of the outcomes can affect the size of the FRN such that infrequent outcomes elicit larger FRN amplitude. However, in the MID task positive outcomes were more frequent than losses, and thus should not have produced a larger FRN. In fact, based on frequency of the outcomes, losses should have been less expected and produced a larger FRN compared to wins. Moreover, the wins on the task should have elicited a reward positivity, which would have further attenuated the FRN amplitude. Thus, the results of this study were inconsistent with previous literature and

could not be intuitively explained with the reinforcement learning theory of FRN production.

The two major differences between the tasks were the presence of informative cues and the perceived sense of control on the MID task.[2] Presence of informative cues might have provided participants with enough information regarding the valence of the trial, emphasizing the achievement of task goals at the time of the outcomes. However, in this case, the FRN would be attenuated rather than amplified, as some of the dopaminergic activation would have occurred at the time of the cue, resulting in a smaller change in dopamine levels at the time of the outcome. Finally, if participants did have a perceived sense of control over the outcomes they might have engaged in predictions regarding the outcome in the time after the response but prior to the presentation of the feedback. Although participants could have expected to lose on each trial, thus making wins less expected and more salient, there was no objective reason for such expectations. As mentioned earlier, wins were more frequent and, thus, more probable than losses. Furthermore, low levels characteristics such as frequency and probability of wins were about the same in both tasks, so it is unclear as to why individuals would expect to lose more often on the MID task but win more often on the gambling task. It seems that some more global task characteristic modulated the FRN valence effect causing an unexpected pattern.

As previously discussed, a number of complex cognitive constructs and judgements were shown to modulate FRN amplitude (e.g., Li et al., 2010; Long et al., 2012). These constructs arise from integration of many levels of information (i.e., from

[2] Note: Participants had no real control over the outcomes as the task was set up to result in losses one third of the time.

basic perceptions to utilization of previous experience and memory) in order to set a subjective value of the stimulus. Previous research on localization of function has shown that tertiary cortical zones are responsible for integration of information, especially in the frontal lobes. For example, the overall task goals would be 'kept' in working memory, integrity of which relies on the functioning of the dorsolateral PFC (e.g., Levy & Goldman-Rakic, 2000). This information is then projected to the medial PFC and integrated in the response of the reward network. It has been shown that medial-frontal cortex is sensitive to subjective value of the stimulus (Kable & Glimcher, 2007) and, as previously mentioned, frontal structures have direct connections with the ACC (Vogt & Pandya, 1987; Devinsky et al., 1995). Thus, there is no reason why this information could not be projected to the ACC in order to influence its responses to the stimuli (i.e., decisions regarding salience of a stimulus). If this is the case, subcortical areas may be more focused on objective (i.e., relatively low level) stimulus characteristics (such as frequency of occurrence), while more complex constructs (subjective stimulus characteristics) are processed in higher cortical areas. Information from both streams would then be conveyed to the ACC, which then inhibits activations to non-relevant stimuli, in turn increasing activation to relevant ones.

Differentiation between the two streams (i.e., objective vs. subjective stimulus characteristics) can be done by manipulating expectations through either frequency/probability of the outcome (i.e., objective) or by manipulating the individual's cognitive state at the time of the outcome presentation (i.e., subjective). Individuals learn the probability of a stimulus based on previous experience of its frequency (a low level characteristic), and thus, this information can be coded in subcortical areas (e.g., ventral

stratum). Manipulation of expectations through instructions requires more complex processing and integration of information (e.g., source of information, previous experiences), which is then projected from frontal cortex to ACC and other subcortical areas. The goal of this dissertation research was to propose a more comprehensive model of FRN modulation, which could account for effects of complex cognitive constructs on the FRN.

Proposed model

According to the proposed model (Figure 1.2), an outcome stimulus (e.g., win or loss) that is presented to the individual contains information that will be processed by subcortical and cortical areas of the brain. More specifically, neurons in the subcortical areas (basal ganglia) will code information about low level stimulus characteristics (e.g., frequency, value, magnitude) and project it to the ACC. Complex cognitive constructs, such as task goals, will be coded in higher cortical areas (e.g., PFC) and input from these areas will also have an effect on the response of the ACC as the prefrontal cortex has direct connections with the ACC (Bjorklund & Dunnett, 2007). Thus, it would be plausible to assume that the activity of the ACC is modulated by both top-down projections from the prefrontal cortex as well as bottom-up projections from the basal ganglia.

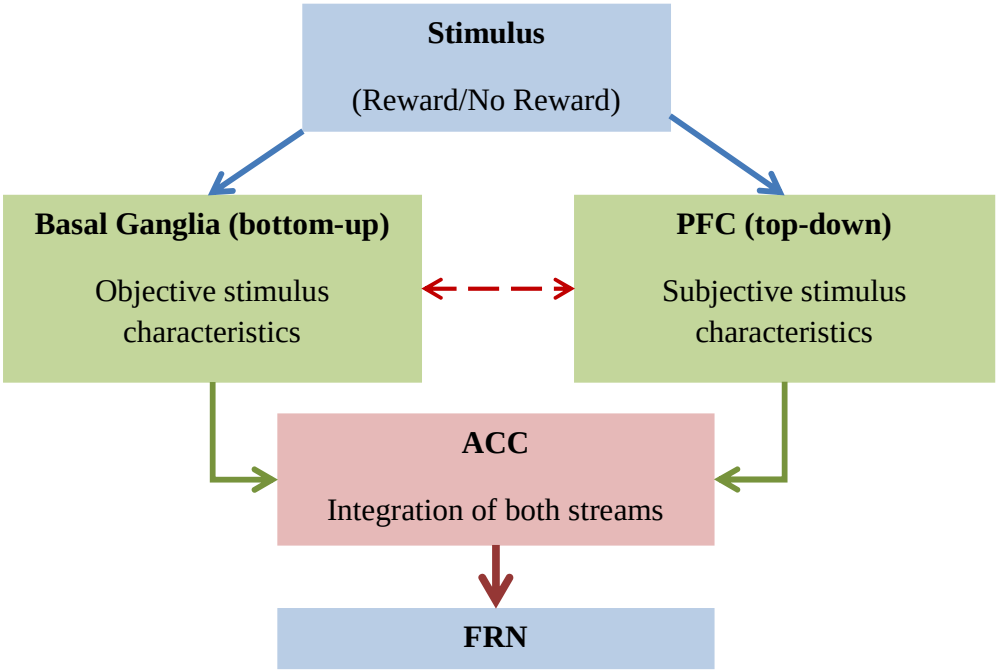

Figure 1.2. Schematic representation of the proposed model of FRN generation.

Based on the proposed model, a neutral stimulus (e.g., in the balloon task used by Holroyd et al., 2004) presented in a 'loss' trial (i.e., in which it is the best possible outcome) will be processed by the basal ganglia and the prefrontal cortex. This stimulus has no objective reward value associated with it, thus the dopaminergic changes in subcortical areas will be relatively minor. However, the subjective value of the stimulus is positive, as it is the best possible outcome in this type of trial. This information will be coded by the medial prefrontal cortex and then projected to the ACC. Similarly, a neutral stimulus presented during a 'win' trial will have a negative subjective value, which also will be coded in the medial prefrontal cortex. In this scenario, the difference in activation of the ACC in each type of trial will be based on the top-down projections (i.e., from the frontal areas) rather than bottom-up (i.e., from the subcortical areas), as the latter does not differentiate between the trials due to equivalency in the objective value of the stimulus.

It must be noted that this is a very simplified model of the system, as there are a number of interconnections between these structures. For example, the ventral tegmental area projects to the prefrontal cortex (Vogt & Pandya, 1987) and prefrontal cortex is connected to the nAcb. Similarly, the projections between ACC and prefrontal cortex are bidirectional (Bjorklund & Dunnett, 2007). However, given the relatively late timing of the FRN, it is likely that this component reflects a result of *contextual* processing (i.e., stimulus + the cognitive state of the individual) rather than objective stimulus characteristics. Furthermore, if the information regarding the subjective value of the stimulus is processed in the prefrontal cortices and then projected to ACC indirectly (i.e., through subcortical areas), then this dopaminergic signal produced by the basal ganglia will reflect an interaction between these characteristics. In this case, objective and subjective stimulus characteristics will not be dissociable at the level of the ACC activity (i.e., FRNs). As EEG technology does not directly measure activity of the subcortical areas, this model could not be tested directly. However, it was hypothesized that the proposed model of FRN generation (i.e., with direct connections between the PFC and ACC) would be supported only if the manipulations of subjective (defined by various cognitive factors) and objective stimulus characteristics can be clearly dissociated at the level of the FRN.

Goals for the dissertation research.

The purpose of this dissertation is to evaluate the proposed model by examining the effects of cognitive factors (sense of control, expectedness of the outcome based on instructions) and objective stimulus characteristics (valence, expectedness based on probability, presence of informative cue) on the FRN within individuals as well as

compare the responses to reward-based information in two populations (individuals who do not gamble and those who are at risk for problem gambling). The effects of informative cues and sense of control over the outcome was examined in Study 1. Participants were asked to complete a series of tasks which varied in level of control over the outcome: observing choices made by a computer, guessing which card leads to a reward and responding to a target within an allotted amount of time. Each task was presented with or without an informative cue. The study was designed to allow for the dissociation of the effects of predictive cue (i.e., bottom-up) and sense of control (i.e., top-down) on the FRN amplitude.

In Study 2, the model was tested further by comparing individual's responses to tasks varying in sense of control as well as by comparing the responses of two different populations. More specifically, participants were asked to complete a time estimation task, with a perceived sense of control over the outcome and perceived levels of difficulty, and a gambling paradigm where participants had no sense of control and were explicitly asked to predict the outcome. In the gambling paradigm, predictions were based on the probability of positive outcomes and, thus would reflect information contained in the bottom-up projections to the ACC. In the Time Estimation task, frequency and probability of the outcomes were kept equal, so any effects of expectations would be solely due to the instructions given (i.e., top-down projections to the ACC). Comparison between the two tasks allowed us to examine the relative effects of these factors on the FRN amplitude, and thus the ACC activity. The proposed model was further tested in Study 2 by comparing the FRN observed in two populations: problem gamblers and non-gamblers. These results were used to clarify the role of individual

differences (e.g., previous experience, cognitive distortions) on the activity of the ACC. Together the results of the studies should provide insight into the task characteristics that can affect the FRN, and therefore ACC activity and provide support to the proposed model of FRN generation.

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Study 1: Effects of sense of control and presence of an informative cue on the Feedback Related Negativity

In the original Dzyundzyak (2010) study, participants were asked to perform two tasks where reliance on external feedback for performance evaluation was necessary. Feedback on each task elicited an FRN similar in latency and topography, and the FRN to loss feedback was of similar amplitude in the two tasks. However, in comparison to the loss-FRN, the FRN observed after wins was significantly smaller in the gambling task and significantly larger in the MID task (i.e., wins elicited a larger FRN then losses). This effect was unexpected and not consistent with previous literature (e.g., Gehring & Willoughby, 2002; Kreussel et al., 2012). As participants produced a classic FRN-valence effect in one task but not in the other, it is likely that some difference in task characteristics modulated the FRN response. Thus, Study 1 was designed to examine the effects of these differences on the FRN amplitude.

The tasks differed in two ways. In the gambling task, participants received no information regarding the potential outcome of the trial; all trials resulted in a win or a loss, and participants reported no sense of control over the outcomes or ability to develop a strategy. In the MID task, participants were first shown a cue that labeled the trial as a potential win/loss, eventually leading to four possible types of outcomes (win, no win, loss, no loss). The FRN on this task was not sensitive to the differentiation between the four types of outcomes; instead, consistent with previous literature, only successes (i.e., win & no loss) and failures (i.e., loss & no win) were discriminated (e.g., Hajcak, Moser, Holroyd & Simons, 2006). Additionally, participants reported having a sense of control over the outcome in the MID task as well as the ability to develop strategies. Thus, the

two main differences between the tasks were the presence/absence of an informative cue and perceived sense of control over the outcome.

Cue effect

Shultz's body of work on the sensitivity of nAcb to reward-related information shows that this structure is sensitive to the cues predictive of a reward (see Shultz, 2007 for review). Using classical conditioning paradigms, Shultz demonstrated that dopaminergic neurons in the nAcb increase their response to the predictive cue and decreased the response to the outcome as the association between the cue and the outcome is learned. Once this pairing was established, these neurons responded exclusively to the presentation of the cue and not to the presentation of the reward. Although studies with human participants rarely utilize classical conditioning paradigms, learning paradigms are often used (e.g., Bellebaum & Daum 2008). The basic mechanisms responsible for reward processing in humans are likely to rely on the same neural structures as those in rodents (e.g., nAcb/Basal Ganglia).

Knutson and colleagues (2001) examined brain activation of participants engaged in an MID task at the time of cue and outcome presentation. In this version of the task, seven cues were used: potential wins and losses with three levels of magnitude as well as a no-incentive cue. Reward cues led to higher activation of the nAcb when compared to no-reward cues (i.e., a valence effect). Similarly, nAcb activation was observed during the anticipation period of the MID task, which follows the cue and precedes target presentation (Bjork et al., 2004). Activation of both the nAcb and PFC were observed at the time of feedback presentation, illustrating that both structures are involved in the processing of outcomes.

The cues used in the MID paradigm did not predict the outcome completely (as would be observed in classical conditioning paradigms) but still elicited activation of the nAcb. If the mechanisms of reinforcement learning outlined by Shultz (2007) can be generalized to humans, activation of the nAcb at the time of the cue should diminish the response at the time of the outcome. As these cues were not completely predictive of the outcome, activations of dopaminergic neurons at the time of the cue would never abolish activation at the time of the outcome. Instead, one would expect the neural response to the reward to be distributed across the times of the cue and reward. If the FRN reflects dopaminergic signal to the ACC from the basal ganglia, then presence of informative cues should affect the magnitude of this signal.

The effects of a predictive cue on the FRN were explicitly examined by presenting participants with three types of cues prior to presentation of the outcome (Xu et al., 2011). The cues could signify a certain win, a certain loss or an uncertain outcome. The feedback was then presented to inform the participants of the valence and magnitude of the outcome (e.g., +5yuan). Feedback after cues signifying certain outcomes (i.e., win or loss) elicited a larger FRN following losses compared to wins. Feedback following the uncertain cue also elicited an FRN-valence effect in the expected direction, which was larger in magnitude than that observed on the certain-cue trials. The authors also reported observing an FRN-like component after the uncertain cues that was similar in size to the FRN observed after loss outcomes on the same trials. Thus, if the FRN is a marker for change in dopaminergic activity, the results can be interpreted as evidence for dopaminergic activation at the time of the cue as well as the outcome. When the pairing between a cue and an outcome was certain (e.g., certain win cue), dopaminergic

activation at the time of the feedback presentation was reduced, presumably due to reduced value of it as a source of new information. As the cues were predictive of both wins and losses, this resulted in a smaller overall differentiation between the two in the FRN (i.e., smaller valence effect). Although the authors did not examine electrocortical responses to the certain gain/loss cues, one would expect to see a cue-FRN component that was larger after certain loss cues than certain win cues. On the uncertain trials, when the cue is not completely predictive of the outcome, activation at the time of the cue does not replace the activation at the time of outcome delivery. Instead, presence of an uncertain cue led to a greater activation at the time of outcome presentation. Thus, presence of a cue prior to outcome modulated the amplitude of the FRN.

Effects of presenting a cue on the outcome can be more clearly seen when cues predict the outcome in a probabilistic nature. These cues can be used to set up the participant's expectations, which then modulate the FRN. Holroyd, Krigolson, and Lee (2011) have shown that wins following a 'low probability win' cue (i.e., unexpected wins) elicit a larger positivity at the time of the outcome, thus decreasing the size of the FRN. Conversely, unexpected losses elicited the most negative FRN. Additionally, the cue-FRNs differentiated between the cues of different probabilities, such that high probability loss cues elicited by a larger cue-FRN. The authors interpreted this result as a positivity that is elicited by reward cues, which then influences the response at the time of the FRN. This interpretation would be consistent with Shultz's work (2007), as predictive cues elicited a dopaminergic response, and further supports the notion that cues influence responses at the time of the outcome. This interpretation is also consistent with reinforcement learning theory of FRN generation (Holroyd & Coles, 2002). If FRN

is generated by the dopaminergic signal to the ACC, it is expected that rewards and omission of rewards (i.e., punishments) will result in increase or depression of dopamine levels in the basal ganglia, respectively. The direction of change (activation vs. depression) reflects the valence of the outcome and is reflected as either a positivity or a negativity at the scalp.

Thus, it is likely that presence of a cue in the MID task had an influence on the FRN observed at the feedback stage. Although, the cues are not completely predictive of the outcome, they carry valence information labeling the trial as potential win/loss. Given previous research on the topic (Holroyd, Pakzad-Vaezi, & Krigolson, 2008; Xu et al., 2011), it is expected that presence of cues in each trial should either attenuate the FRN at the time of the outcome or increase the size of the valence effects due to presence of reward positivity. However, as neither of these effects were obtained it is unlikely that presence of the cue alone caused the reversal of the FRN-valence effect observed.

Sense of control

Another difference between the tasks was the perceived sense of control on the MID task reported by the participants. At the debriefing stage participants reported trying to develop strategies for the MID task, but said that their responses and outcomes on the gambling task were random. There are two possible effects of these perceptions on the participant's cognitive state at the time of feedback presentation. Perception of control over the outcome could have increased participants' motivation and made the feedback stimuli more salient. Previous research has shown that the FRN amplitude is attenuated if the outcomes are not driven by participant's choices (e.g., when a computer chooses a card; Yeung, Holroyd, & Cohen, 2005; Bismark et al., 2011). A diminished sense of

responsibility was also shown to decrease the FRN-valence effect (Li et al., 2011). In this experiment, participants were asked to perform a gambling task with three dice; a trial was considered a win if the sums of three dice thrown was greater than 10. In a high responsibility condition, participants threw all three dice, whereas in the low responsibility condition participants threw only one of the three dice. The FRN following loss trials was larger compared to the FRN following win trials. Although valence effects were observed in both conditions, the size of this effect was larger in the high responsibility condition. Therefore, increased engagement on the task should lead to an increase either in the amplitude of the FRN or the size of the FRN-valence effect. As neither of these effects was observed in the original study (Dzyundzyak, 2007), it is unlikely that increased involvement in the outcome was the reason for the reversal of the FRN-valence effect.

Perception of control of the outcome could also lead to increased confidence in one's predictions of the outcome. In the MID task, participants were told that in order to obtain a positive outcome they have to press the response key while the target was still on the screen. The outcome was shown about a second after the response was made, giving participants enough time to form expectations. Unlike in the gambling task, the structure of the MID task allows the participant to predict performance (i.e., by comparing the duration of the target and the perceived speed of own response) and evaluate the feedback presentation based on the degree of conflict with expectations rather than its valence. In this case, unexpected outcomes might elicit a larger prediction error increasing the amplitude of the FRN. However, given the speeded nature of the task it may have been difficult to tell whether the response key was pressed while the target was

on the screen, so it is likely that participants' predictions of the outcomes were inaccurate and varied with their ability to accurately monitor their reaction times. Although positive outcomes were more frequent, participants may have predicted success less often (i.e., wins being less expected). If wins were less expected compared to losses, the FRN amplitude would reflect that by being larger following wins than losses. Although, this is consistent with results of Donkers et al. (2005), showing larger FRN amplitude following unexpected wins, this is inconsistent with the model of reward positivity. Based on the work of Holroyd et al. (2008), wins should have elicited a reward positivity (not a greater negativity), and this positivity should have increased as a function of the unexpectedness of the outcome and thus lead to more positive FRN. In this case, the expectations alone should not have led to a reversal of the FRN-valence effect. However, previous research has also shown that presence of a predictive cue could initiate reward positivity prior to presentation of feedback (Holroyd et al., 2008; Holroyd et al., 2011). Although it is unlikely that this positivity would last from the onset of the cue to the presentation of feedback (at least 2 seconds), it is possible that once valence information of the trial was processed, feedback was viewed to be devoid of any reward information and did not elicit a reward positivity. Thus, an interaction between the presence of a cue and sense of control over the outcome could have led to the reversal of the FRN-valence effect (e.g., Figure 2.1).

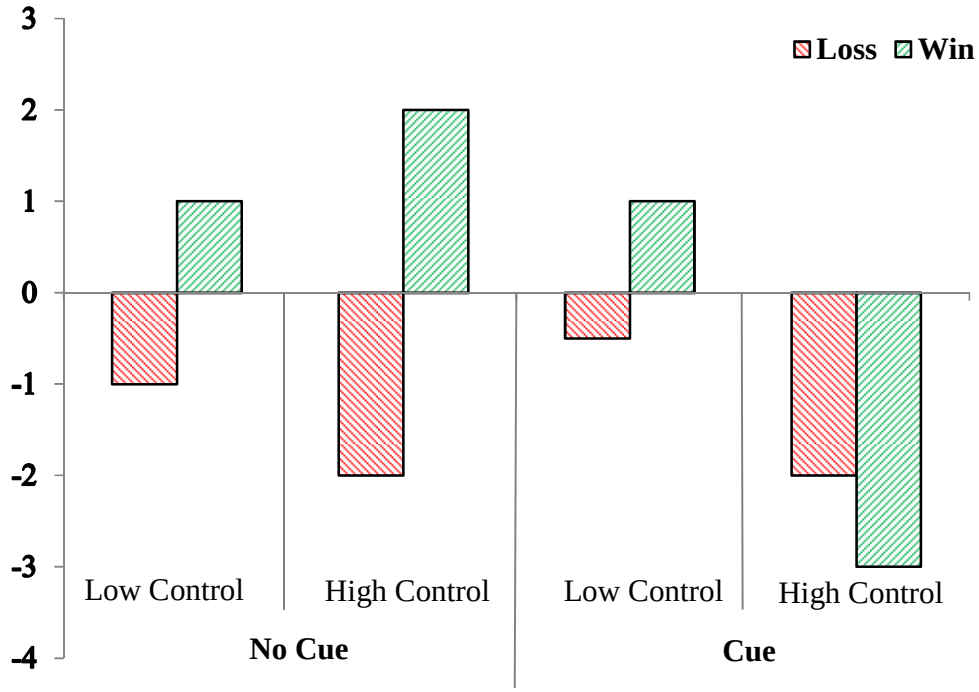

Figure 2.1. Graphical representation of the expected effects of cue and sense of control on the FRN amplitude.

Current study

This study was conducted to examine the effects of cues and sense of control on the amplitude of the FRN by using two levels of cues and three levels of sense of control. Three versions of the task contained cues that were informative, labelling the trial as a potential win or a potential loss. The other three had a non-informative cue that simply signified a start of a new trial. On each trial participants were presented with a cue (either non-informative or containing valence information) followed by the appearance of two cards that represented gambling results for that trial. In the 'No-Control' condition participants had to press a button to initiate the computer to choose a card for them. In the 'Some-Control' condition, participants chose a card themselves and in the 'Full-Control' condition participants had to press a button while the cards were still on the

screen in order to win. Following a response participants were presented with the trial outcome.

Additionally, these condition characteristics will be used to test the proposed model of FRN generation. If the model is correct, presence of informative cues should be coded in the subcortical areas and projected to the ACC. For the purpose of this study, any effects of cues on the FRN will be interpreted as evidence for bottom-up input to the ACC. Similarly, effects of sense of control will be interpreted as influences of higher cortical areas on the ACC (i.e., top-down projections).

Hypotheses

1. Sense of Control (top-down). It is expected that the FRN amplitude or FRN-valence effects will be attenuated with diminishing sense of control.

(a) The FRN will be most sensitive to feedback valence in the 'Full-Control' condition.

(b) The 'No-Control' condition should mirror the results observed by Li et al. (2011) in the diffusion of responsibility condition as participants are not completely in control of the outcome, and therefore are expected to have the smallest difference between the FRNs elicited by wins versus losses. This hypothesis is based on previous research suggesting that engagement in the task increases FRN sensitivity to valence (e.g., Yeung et al., 2005).

(c) Reward positivity amplitude should not be affected by sense of control manipulation, as this signal was proposed to arise from subcortical areas (i.e., bottom-up projections).

2. Cues (bottom-up). Presence of cues is expected to either (a) attenuate FRN amplitude, as valence of the trial will be known ahead of time, or (b) have no effect at all, as the events are temporally relatively far apart.

   (c) Reward positivity is expected to be smaller following informative cues, as the cues were shown to elicit a positivity at the time of its presentation (Holroyd et al., 2011).

3. Interaction effect. An interaction effect between cues and sense of control is expected, such that 'full-control + informative cue' condition will produce a reversal FRN-valence effect observed in Dzyundzyak, 2007.

Experiment 1: Methods

Participants

Participants (N = 13)[3] were recruited at Brock University through on campus posters and university research database (SONA). Participants were 19.8 years old on average (range: 18 to 25) and the majority were female (n = 10; 76.9%); none reported smoking, taking any types of medication, or experiencing recent stressors. Most participants were right handed (n = 9, 69.20%). Two participants scored in the low risk range for problem gambling behaviour and one participant scored in the moderate range (25%). One of these participants (low risk) took too long to complete the tasks, was very restless during the recording, and reported not engaging fully in the tasks. Additionally, this participant did not complete the No cue/No-Control condition and, thus, was excluded from further analysis.

[3] Data collection was halted due to lack of participants at the end of the term; collected data were analysed for a validity check prior to continuation of the study.

Materials

Questionnaires.

Demographic information about age, sex, neurological conditions and recent stressors was collected using a demographic questionnaire (see Appendix 1.1 for the questionnaire package). Handedness was measured using ten questions inquiring which hand would be used to carry out everyday activities (e.g., which hand is used to throw a ball?). The responses were measured on a 5-point scale, ranging from *always left* (zero) to *always right* (five) with a *not sure* (six) option (Oldfield, 1971).

Participants were also asked to complete a *Problem Gambling Severity Index* (PGSI; Ferris & Wynne, 2001) to collect information about maladaptive gambling behaviour. This questionnaire consists of nine questions about frequency and consequences of gambling behaviour (e.g., Have you bet more than you could really afford to lose?). Participants were asked to respond using a 4-point scale, which ranged from *never* (zero) to *almost always* (three). According to the scoring criteria, anyone scoring between one and three was labeled as low risk problem gambler and those with scores above eight were considered high risk problem gamblers (Ferris & Wynne, 2001).

Additionally, after each sense of control condition participants were given a *Post-Task Questionnaire*, assessing their experience during the task on a 6-point scale (*not at all* = 0 to *all the time/usually/most of the time* = 5, depending on the question). Importance of the cue information (e.g., Were the cues helpful?), sense of control over the outcome (e.g., Did you have a feeling of control over the outcome?), perception of wins and losses (e.g., How often did you feel you would win?) as well as overall

engagement (e.g., Were you paying attention to feedback?) were measured. Participants were also asked to describe any strategy that they used during the task.

Tasks. The tasks were designed to have a similar format and differed in two ways: presence/absence of an informative cue and level of control over the outcome. For detailed description of instructions, visual angles and average number of trials see Appendix 1.3. Participants were given four trials to practice each version of the task.

No-Control condition. At the start of each trial a cue was presented for 500 ms to signify the start of a new trial (Figure 2.2). The cue was either a white square (non-informative), a green square (potential win trial) or a red square (potential loss trial). The task was blocked such that one version of the task included an informative cue (Cue-No-Control) and another a non-informative cue (No cue-No-Control). Otherwise, the two versions of the tasks were exactly the same.

Following the cue, a gray screen was presented for 1, 1.20 or 1.5seconds. The inter-stimulus interval (ISI) was varied to reduce participants' ability to predict the onset of the next stimulus. After the ISI, a target stimulus in the form of two squares was presented on the screen for 700 ms. Participants were instructed to press a key in order to initiate the computer's choice of card. The target stimulus was terminated at the time of response. If no response was made within 700 ms, the target disappeared and a grey screen for an ISI of 1000 ms was presented. After the target stimulus and ISI, both cards reappeared again for 300 ms. One of the cards was highlighted with a blue border, to show which card was chosen by the computer. If participants failed to respond to the target or took longer later than 700 ms to respond, both cards were highlighted with a red border. One second following this stimulus, the feedback was presented in yellow letters

for 1 second. There were five types of feedback, regardless of the cue condition: win, loss, no win, no loss, too slow. The latter stimulus was used to indicate trials where participants failed to respond to the target within 700 ms. All of the outcomes were predetermined to result in a rate of 60% wins overall. Participants' earnings on this task differed only due to the number of *Too Slow* trials, each of which resulted in a loss. Each version of the task (i.e., cue and no cue) was divided into three blocks with 50 trials per block. Self-paced breaks were given to the participants between each block.

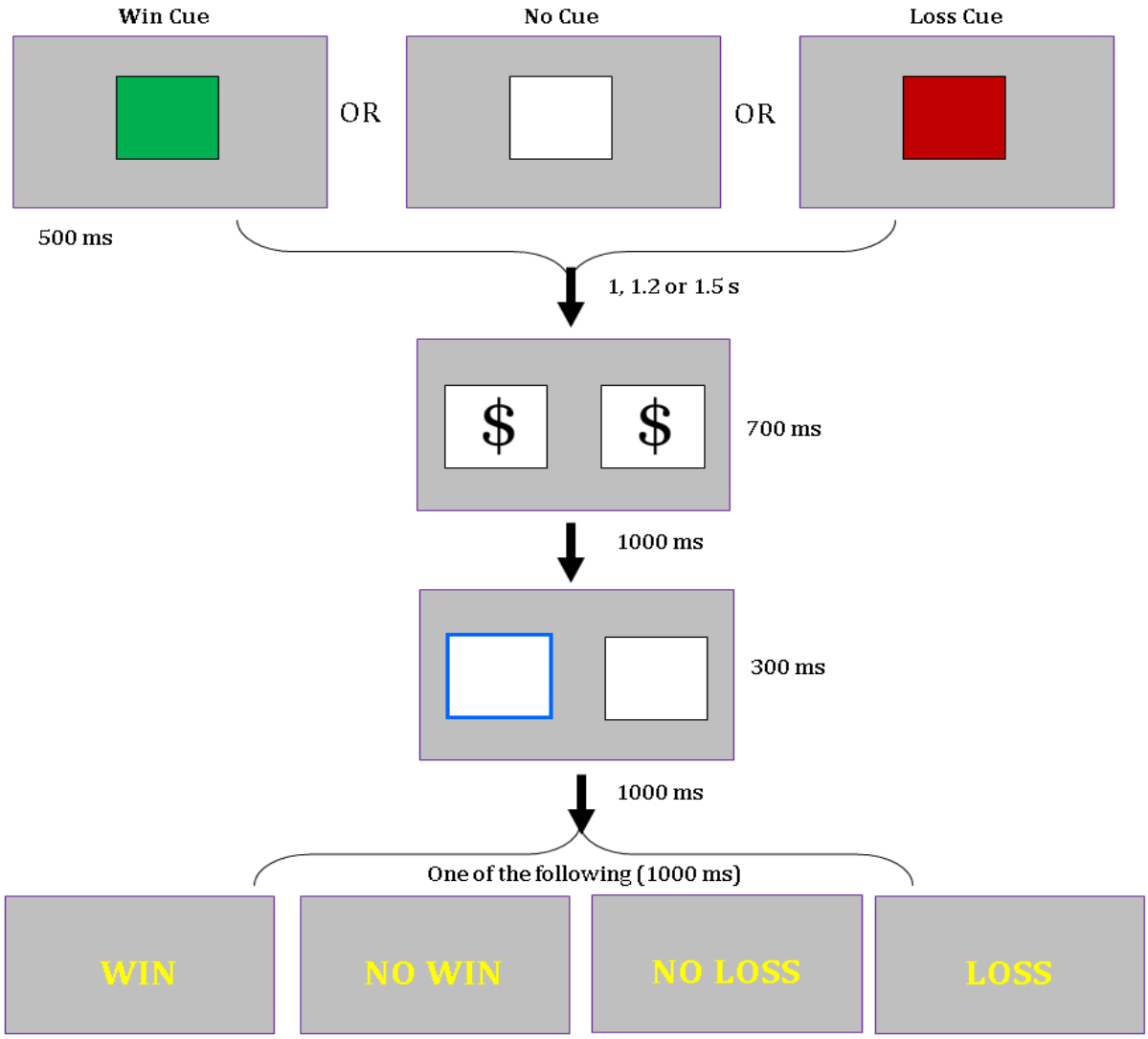

Figure 2.2. Schematic representation of the No-Control conditions.

Some-Control condition. The order and duration of the events in this condition were the same as in the No-Control condition (Figure 2.3). Versions of the task with informative and non-informative cues were presented as separate tasks (Cue-Some-Control and No cue-Some-Control, respectively). In this version of the task, participants were asked to choose a card from the two presented on the screen using two response keys. As in the No-Control condition, participants had only 700 ms to make their response. Once the response was made, the target stimulus disappeared. All of the outcomes were predetermined to produce 60% wins and did not depend on the card chosen. Similar to the No-Control condition, differences in earnings on this task resulted only from the variable number of *Too Slow* outcomes between participants. Participants received two self-paced breaks during each version of the task (3 blocks, 50 trials per block) and a longer break between the cue and no cue versions.

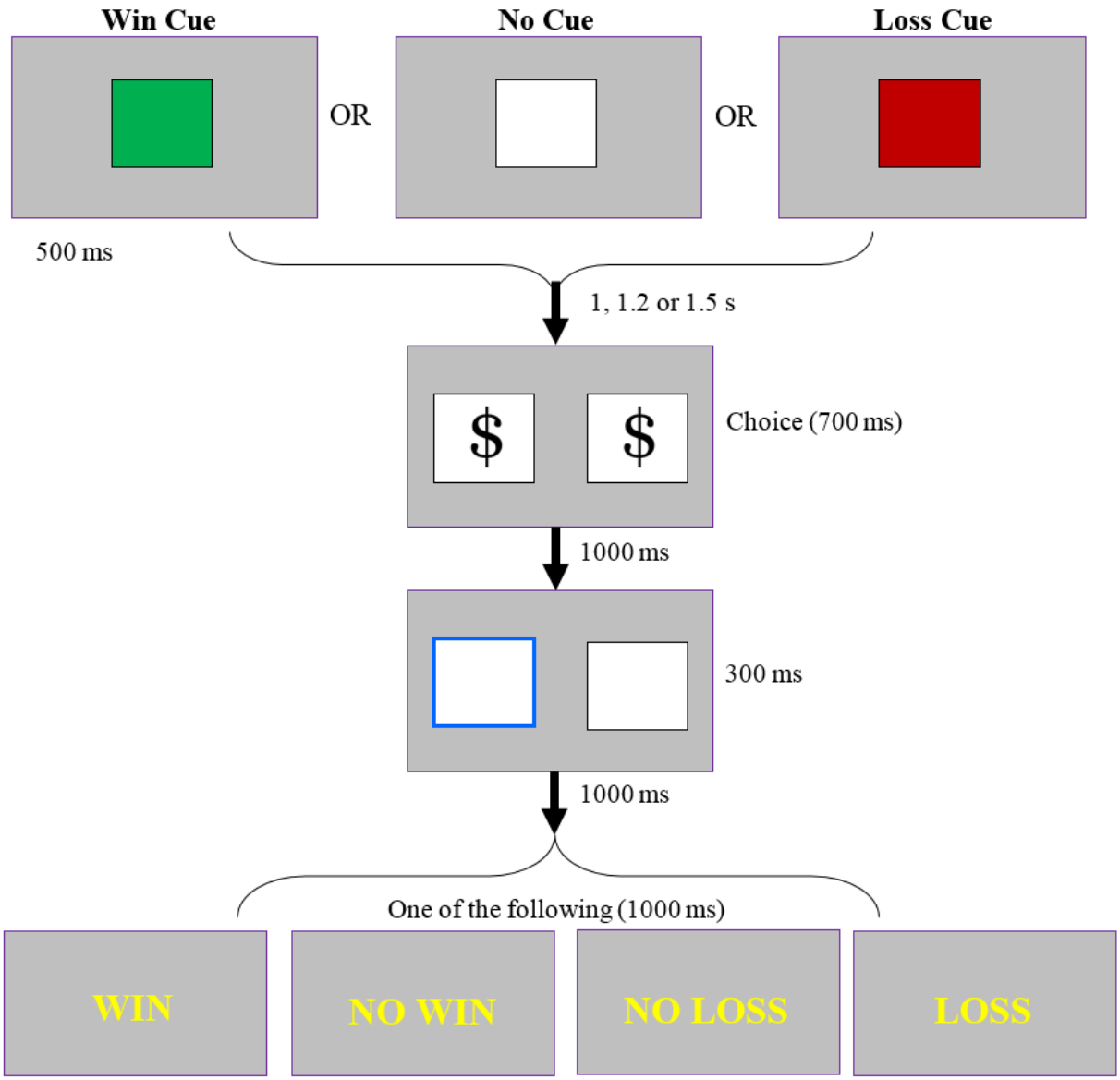

Figure 2.3. Schematic representation of the Some-Control conditions.

Full-Control condition. This version of the task was also further divided into informative cue (Cue-Full-Control) and non-informative cue (No Cue-Full-Control) conditions (Figure 2.4). The beginning of the trial was exactly the same as the previously described versions of the task. A cue appeared at the start of each trial, followed by a variable ISI and a target stimulus. However, in this case, participants were told that they can win or avoid losing money by pressing the response key while the two cards were on

the screen. The initial duration of the target was 280 ms and was adjusted in response to participant's performance (i.e., for every win the duration of the target was reduced by 10 ms, and after every loss increased by 20 ms) to result in wins two thirds of the time. A second after the target stimulus, two cards reappeared on the screen for 300 ms. Although unnecessary in this version of the task, these stimuli were presented in order to be consistent with the No-Control and Some-Control conditions. Both cards were highlighted by a blue border if a response was made at some point, and by a red border if no response was made. Thus, participants knew when the *Too Slow* feedback would appear, but not any of the other types of outcomes. Each trial was worth 50 cents and there were 150 trials in each version of the task (over 3 blocks). As in the No-Control and Some-Control conditions participants were able to take two self-paced breaks after every 50 trials.

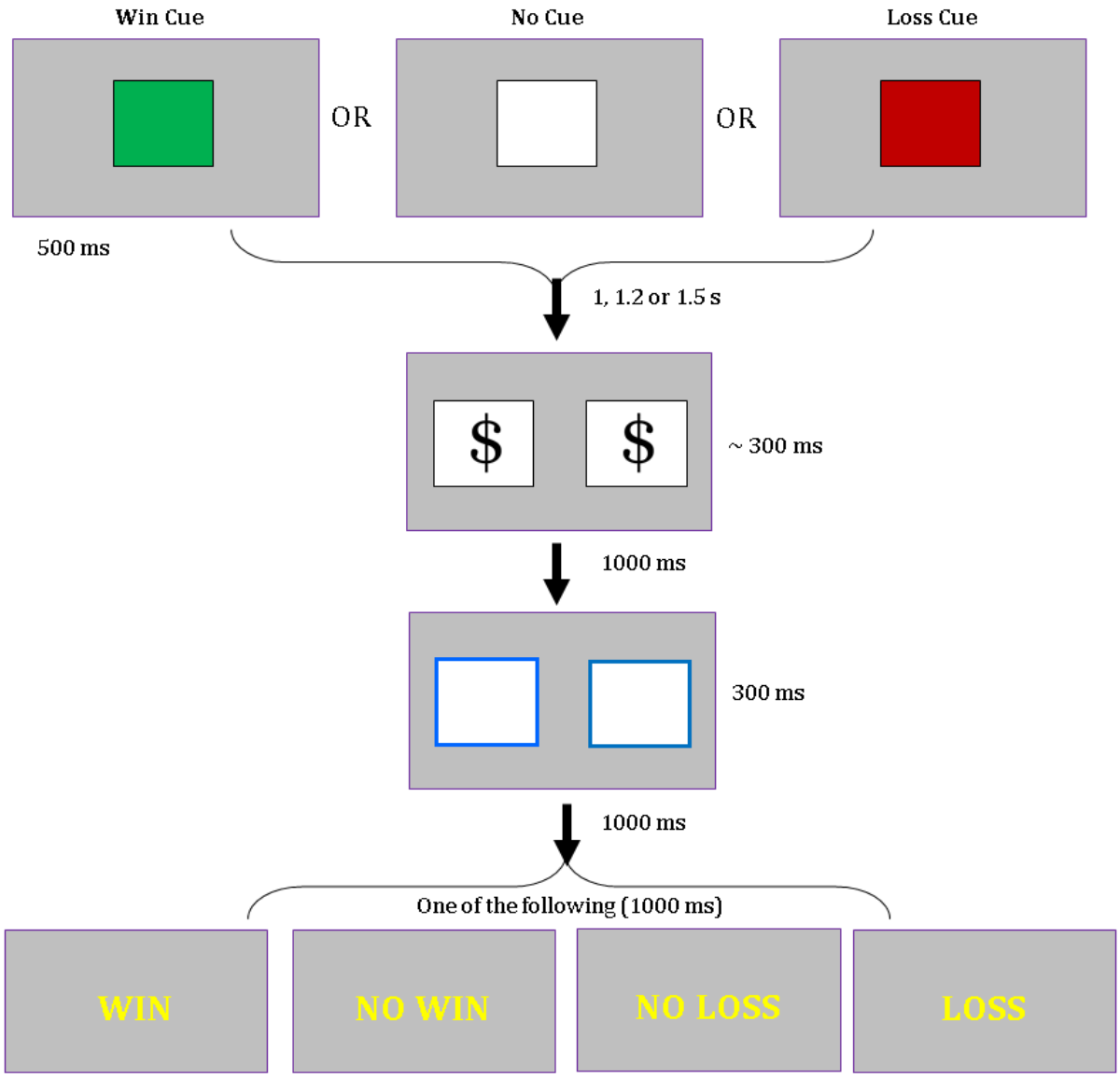

Figure 2.4. Schematic representation of the Full-Control conditions.

Procedure

Participants were recruited using on-campus posters and a university research database. They were screened for neurological conditions (e.g., epilepsy), mental health problems (e.g., depression) and head injury during a phone interview. At the beginning of the testing session, participants were informed about the study and gave their consent to participate. Individuals were then fitted with an electrode cap and asked to sit down in

an electrically shielded testing room. During the fitting of the cap, participants were asked to complete the demographic questionnaire and the PGSI. Once the electrodes were placed into the cap, participants were shown the online recording of their brainwaves and explained the effects of muscle activity on the EEG recordings. Participants were then asked to complete the six versions of the task. Each testing session took about three hours.

The order of task presentation was counterbalanced, such that at the end of the study all of the counterbalancing combinations were completed by at least one participant. Counterbalancing was done across the three levels of sense of control and then by the type of cue participant (see Appendix 1.3 for the list of the counterbalancing order). After each set of tasks for a specific level of sense of control (e.g., Cue-No-Control and No Cue-No-Control) participants were asked to fill out the *Post-Task* questionnaire.

Upon completion of the task and the last questionnaire, the electrode cap was removed and participants were given time to clean up. Finally, the research question explored by the study was explained to the participants in the debriefing process. Participants were then paid based on their performance. Monetary reward was based on the earning in the tasks such that participants received the highest amount won across all the tasks. The average amounts won in each condition are presented in Table 1.1. This study was approved by the Brock University Research Ethics Board (see Appendix 1.1)

Data analysis

EEG pre-processing.

The EEG was recorded with a 128-channel Active Two BioSemi system (BioSemi, Amsterdam). Two additional exogenous electrodes were placed beside each eye to

monitor horizontal movements and one exogenous electrode was placed below the right eye to monitor eye blink activity. The BioSemi system uses zero-reference and the digitized analog signal was stored at 512 samples per second, with a low pass filter with half-power cut-off at 102.4 Hz. The recordings were exported from the BioSemi format to EEGlab Version 11 format (Delorme & Makeig, 2004). Any non-task periods of time (e.g., breaks) and bad channels (labeled as such after visual inspection of the raw data) identified in the recording were manually eliminated. The data were pre-processed using the procedure outlined by Desjardins and Segalowitz (2013) and submitted to an automated, extended infomax independent components analysis (ICA; Bell & Sejnowski, 1995; Makeig, Debener, Onton, & Delorme, 2004). Once ICA decomposition was performed, any independent components (ICs) with activations and topographies consistent with eye movement and muscle activity were eliminated and the scalp data were recalculated (i.e., projected back to the scalp) based on the remaining components.

The data were then segmented around the onset of the feedback stimulus, combining the outcomes into win/no loss (i.e., success) and loss/no win (failure) conditions. The outcomes were combined in order to ensure the necessary number of trials for each condition (see Appendix 1.3 for average number of trials per condition). There were 12 conditions in total, Cue (2) x Control (3) x Win/Loss (2) (e.g., Cue-No-Control win, Cue-No-Control loss). Each epoch contained a 200 ms pre-stimulus baseline and was 1200 ms in length. After segmentation, the data were further cleaned using the automatic artifact rejection tool available in the EEGLab. Each segment was analysed for changes in amplitude that exceeded the set parameters (±100 μV). The segments were also manually rejected if they contained more than one stimulus-marker. During the initial

cleaning procedure, some segments of time were marked as 'bad' (i.e., having too much non-biological noise) and were removed from the recording prior to segmentation resulting in several event markers to appear closer in time on the recording. Thus, if during the segmentation the specified time window (i.e., 1200 ms) previously contained a 'bad' time period that was removed, the data would contain more than one event marker and would not be relevant for the analysis of interest. This was observed rarely, and all such segments were removed prior to further analysis. The data were then averaged and exported to ERPScore (Segalowitz, 1999). Global Field Amplitude (GFA) was also extracted from the segmented (but not averaged) data to be used for the follow up robust ANOVA analysis.

As the Biosemi montage used in this study does not correspond to the 10-20 system perfectly, a number of channels with locations similar to Fz (C14, C13), FCz (C12, C11), Cz (C10, A1, A2) and Pz (A18, A17) were identified (see Appendix 1.3). The FRN, defined as the most negative peak between 200 and 320 ms, was scored across these midline sites. To reduce the number of statistical comparisons and to take into account individual differences in brain structures and variation in activation of the ACC across conditions (which was not a variable of interest in this study), a channel with the maximal FRN amplitude was identified for each condition. This reduced the number of channels to four, which henceforth will be referred to as Fz, FCz, Cz and Pz.

Statistical analysis.

Prior to conducting any inferential statistical analysis, the data were screened for outliers and violations of normality. None of the variables of interest contained outliers. If normality was violated, non-parametric tests were used to address the research

question. Repeated measures ANOVAs were used to examine the effects of cue and sense of control on the FRN amplitude. If assumptions of sphericity were violated, significance values based on Greenhouse-Geisser correction and original degrees of freedom were reported.

Results

Validity check

The responses on the *Post-Task* questionnaire were compared across different levels of sense of control (Figure 2.5 and Table 1.2). As the data were not normally distributed and the sample size was small (N = 12), no statistical comparisons were conducted. Participants appeared to pay a similar amount of attention to the cues and found the cues to be equally helpful across all three conditions. A similar pattern of responses was observed for the feedback presentation, but participants reported paying slightly less attention to the feedback and found it less helpful in the No-Control condition. Although the tasks were counterbalanced, individuals reported being more tired/bored after the No-Control condition compared to the other two levels of sense of control. The perceived frequency of wins and losses was similar across the three levels of sense of control.

As expected, participants reported having lower levels of feeling of control over the outcome, being less able to predict the outcome, being less accurate in those predictions and being less confident in their predictions after the No-Control condition. Highest sense of control and ability to predict the outcome as well as highest accuracy of these predictions was reported after the Full-Control condition. Thus, based on self-reported data participants experienced the highest level of sense of control in the Full-Control

condition, followed by the Some-Control condition, and lowest levels in the No-Control condition, suggesting that the manipulation of sense of control was working as expected.

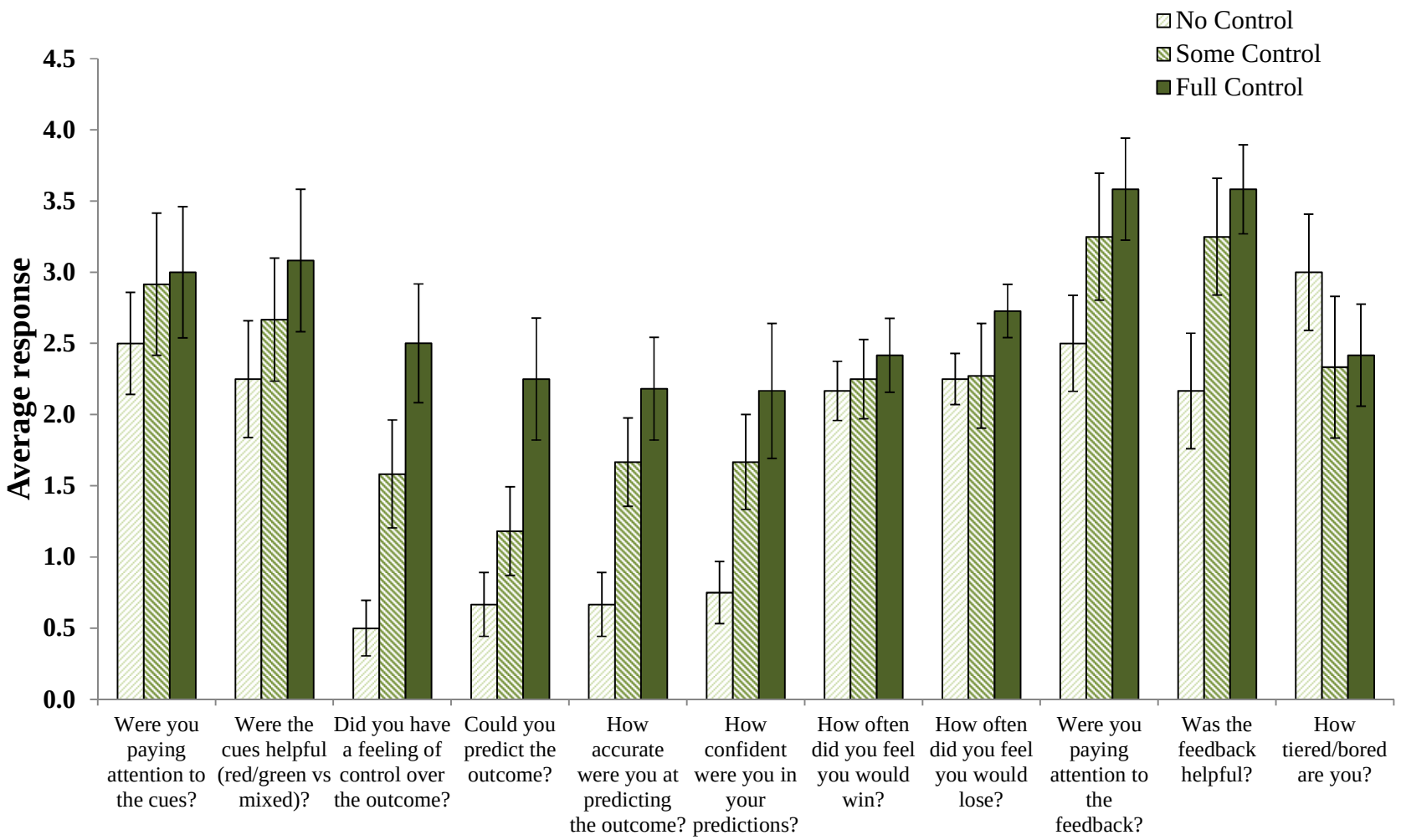

Figure 2.5. Graphical representation of means and standard errors of responses on the Post-Task questionnaire in Experiment 1.

Finally, confidence in predictions was lowest in the No-Control condition and about the same in the Some-Control and Full-Control conditions suggesting that the effect perceived sense of control between these two levels was not as strong. This could be due to the perceived ability to predict random events often observed in gambling situations (i.e., Illusion of Control; Steenbergh, Meyers, May & Whelan, 2002). In order to clarify this result a χ^2 test was conducted to examine the number of people reporting use of strategies across different levels of sense of control. Given the small sample size these results should be interpreted with caution. Overall, participants reported engaging in use of a strategy least frequently in the No-Control condition (n = 2; 16.7%) and half of the participants reported trying a strategy for the Some-Control tasks (n = 6; 50.0%; χ^2 (2) = 3, p = .022). Only four people reported having a strategy for the Full-Control condition (33.3%) and on average participants reported having more sense of control over the outcome in the Full-Control condition. Thus, the manipulation of sense of control was working as expected but the ability to predict outcomes based on this sense of control did not differ between Some and Full-Control conditions.

Behavioural data

Response times (RTs) in each version of the task were analysed across four different types of outcomes (loss, no loss, no win, win) in each version of the task. As the outcomes were predetermined there should be no consistent difference in RT observed in the No and Some-Control conditions. On the Full-Control tasks, the RTs on successful trials (i.e., win and no loss) was expected to be shorter than on failure trials (i.e., loss and no win). In order to test any potential effects of the cue on RTs, a 2 (cue type) x 4 (outcome) repeated measures ANOVA was conducted for each level of sense of control

(Table 1.3). As expected there were no significant effects of cue or valence in the No-Control and Some-Control conditions (see Table 1.4 for *M*s and *SD*s). There was a main effect of valence in the Full-Control condition (F (3,33) = 58.01, p <.001, $p\eta^2$ = .841), such that RT on successful trials (i.e., win/no loss) were significantly faster than RTs on failed trials (loss/no win). Thus, the presence or absence of the cue had no effect of RTs in any of the versions of the task.

ERP data

The FRN was scored as the most negative peak between 200 and 320 ms following the onset of the feedback stimulus (see Appendix 1.4 for overlays of waveforms with original Biosemi channels). In order to increase the power of the comparisons and to ensure at least 40 trials per condition, the outcomes on each trial were divided into successes (i.e., win/no loss) and failures (i.e., loss/no win). Examination of the overlay of waveforms elicited after feedback in the No-Control conditions (Figure 2.6) showed very little differentiation between wins and losses at the time of the FRN. Largest differentiation between conditions was observed in the waveforms elicited in the Some-Control condition (Figure 2.7), such that losses elicited larger FRNs compared to win outcomes regardless of the cue type. The waveforms observed in the Full-Control condition (Figure 2.8) also showed little differentiation between outcomes of different valence at the time of the FRN. All of the conditions elicited a larger FRN at frontal channels.

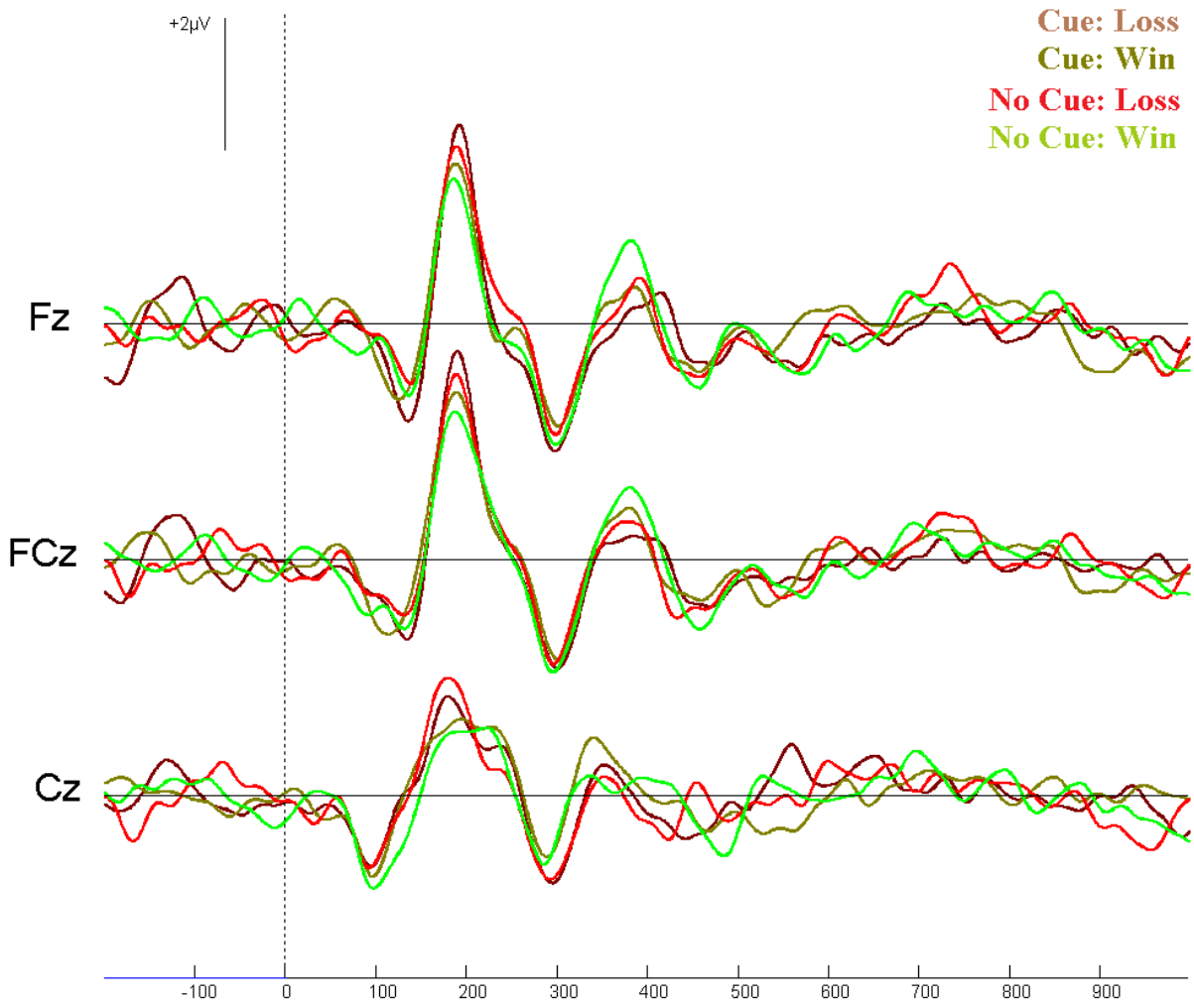

Figure 2.6. Averaged ERP waveforms for the two types of cues and two types of outcomes received in the No-Control versions of the task.

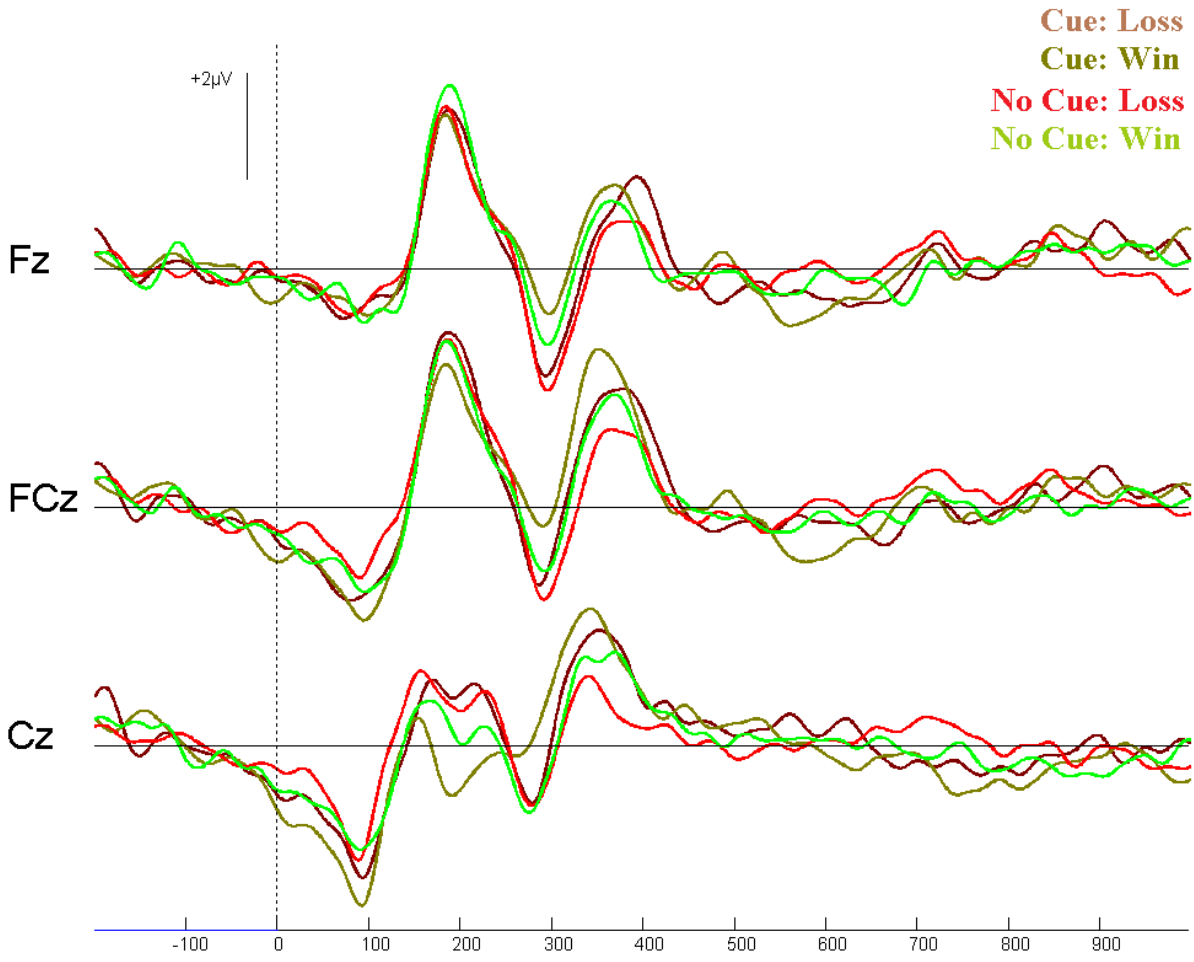

Figure 2.7. Averaged ERP waveforms for the two types of cues and two types of outcomes received in the Some-Control versions of the task.

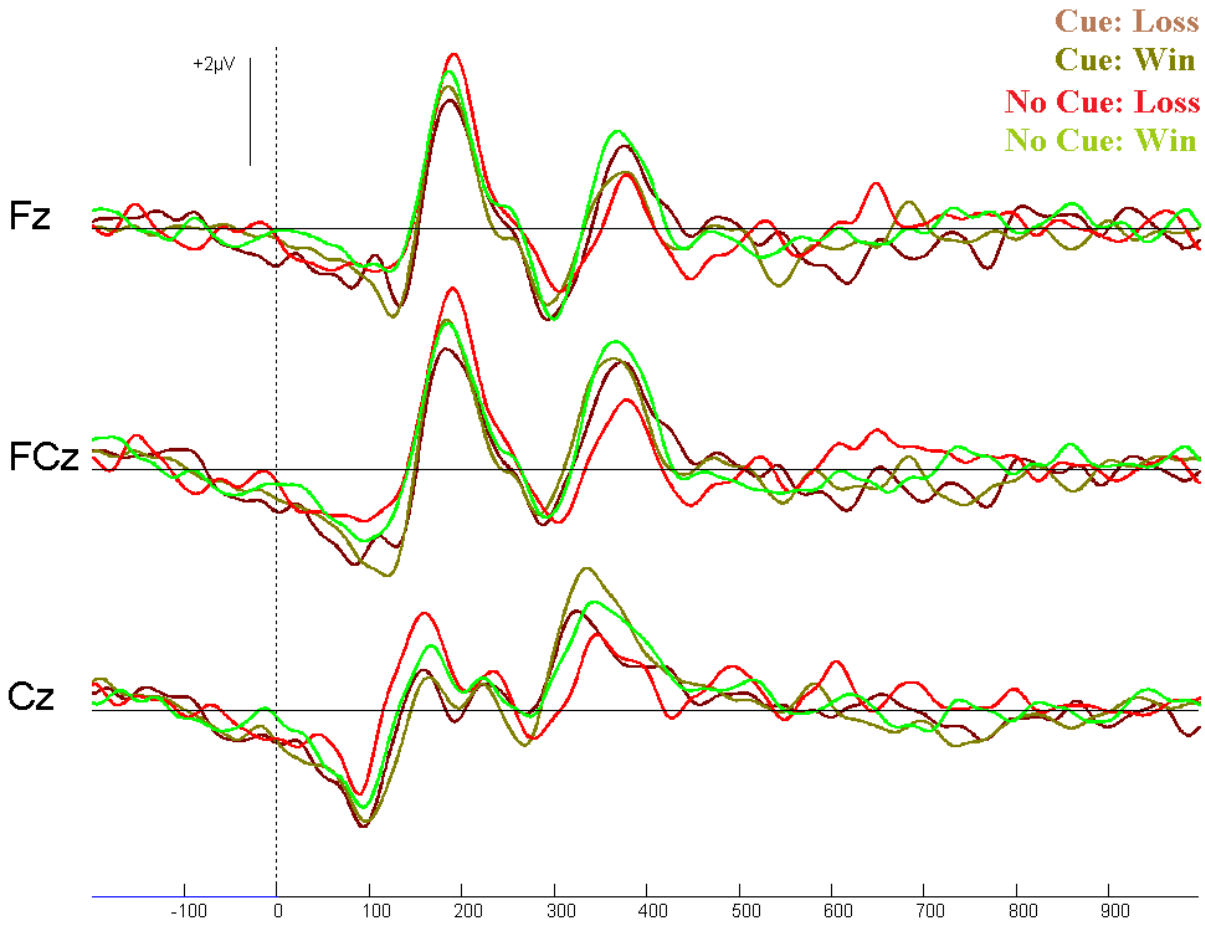

Figure 2.8. Averaged ERP waveforms for the two types of cues and two types of outcomes received in the Full-Control versions of the task.

In order to examine effects of cue and sense of control a repeated 2 (cue type) x 3 (sense of control) x 2 (valence) x 3 (site: Fz, FCz, Cz) ANOVA was conducted (Table 1.5). There was a significant effect of Valence ($F(1,11) = 5.62$, $p = .037$, $p\eta^2 = .338$), such that losses elicited a larger FRN ($M = -1.95$, $SD = 0.41$) than wins ($M = -1.63$, $SD = 0.35$). No other significant effects were observed (see Table 1.6 or *M*s and *SD*s). Thus, neither the cue nor sense of control manipulations had any significant effect on the FRN. To further examine if the results of this study replicated the FRN effects in Dzyundzyak (2010) a 2 (task) x 2 (valence) repeated measures ANOVA was conducted comparing No

Cue-Some-Control and Cue-Full-Control conditions (Table 1.7). No significant effects were observed in this comparison.

Experiment 1 Discussion

No significant effects of cue or sense of control were observed in the analysis of the FRN amplitude. Furthermore, the results of previous study using similar tasks (Dzyundzyak, 2007) were not replicated. There was an FRN-valence effect in the expected direction, but the magnitude of this effect was small, as it disappeared when only two versions of the task were compared. Although it is possible that neither the cue nor sense of control influence FRN amplitude, this conclusion would not be consistent with previous research showing that cues and investment in the task modulate the responses of the ACC (Holroyd, Krigloson, & Lee, 2011).

During the data collection process participants' comments at the end of the testing session suggested that they were not very engaged during the tasks. The results of the FRNs obtained in Experiment 1 are consistent with lack of motivation and engagement in the outcomes of the tasks, as the FRN-valence effects were quite small in Full-Control and No-Control conditions (see Figures 2.7 and 2.8). There could have been a number of factors contributing to this performance, one of which was the length of testing time. On average, each version of the task took about 20 min to complete (i.e., ~ 2 hours of testing time for all six conditions). Participants reported feeling tired and not engaged in the tasks.

Additionally, participants reported feeling that the No-Control condition was very similar to the Full-Control condition as they had to respond within the allotted period of time. Although, the target was visible for a much shorter period of time in the Full-

Control condition, the subjective experience on these two versions was very similar due to the termination of target stimulus immediately after the response in the No-Control condition. This property was included in the task to shorten testing time, as response times are usually much shorter than 700 ms. Unfortunately this led to the perception of the task as 'speeded' and participants reported being unsure if they made the response within the allotted time. Once the researcher became aware of this issue, a description of this task property was added to the instructions.

Finally, the last factor that could have contributed to the lack of expected effects in Experiment 1 was the self-selection bias. The recruitment for the study was done at the end of the term, when many undergraduate students were trying to obtain research participation hours before the deadline for *Introduction to Psychology* course. Although, this course was two-terms in length, a number of individuals left this component of the course until the second term. The study ran for two weeks prior to the deadline and the majority of participants reported participating because it was "the only study available". Thus, motivation and engagement were a problem in this sample and could have affected the results obtained. A second experiment was conducted in order to address these issues by recruiting at a different time of the year (i.e., spring/summer terms) and changing some of the task characteristics to reduce testing time.

Experiment 2

Methods

Participants

Participants (N = 12) were recruited in a similar fashion to Experiment 1 and were on average 21.08 years old (range: 19 to 23). The majority of participants were female (n =

8; 66.7%) and none reported smoking, taking any types of medication, or experiencing any recent stressors. All of the participants were right handed. Two of the participants scored within the low risk range for problem gambling behaviour (16.7%).

Materials

Questionnaires.

The questionnaires given to the participants were exactly the same as in Experiment 1.

Task.

The tasks used in experiment two were adjusted following Experiment 1 in order to decrease the testing time and the perceived speediness of some of the conditions. To address the latter issue, in the Some-control and No-Control tasks, the target stimulus (i.e., the two cards) were not terminated at the time of response and stayed visible to the participant for the full 700 ms. In order to reduce testing time, the No Cue-No-Control condition was eliminated. Additionally, the reappearance of the two cards in the Some-Control condition, which showed participants the chosen card, was considered redundant, as participants were aware of their choice, and was eliminated. Similarly, in the Full-Control condition, presentation of the two cards following the target stimulus was eliminated completely as it did not hold any informative value. This change further increased the similarity between this version of the task and the MID task that was previously used, where feedback was shown one second after the target offset (Dzyundzyak, 2007). There was no change to the order or duration of any other events in the tasks.

Procedure

The recording procedure was kept identical and the tasks were counterbalanced in a similar format to Experiment 1 (see Appendix 1.3). Participants received their winnings at the end of the session, based on the highest amount won across all the tasks (Table 1.1).

Data analysis

The data pre-processing and analysis procedure were the same as in Experiment 1.

In order to examine potential impact of cue and sense of control factors on the reward positivity rather than the N2 component elicited by the feedback in general (as proposed by Holroyd, et al., 2008), difference waves were created for each participant by subtracting waveforms elicited by negative outcomes (i.e., loss/no win) from those following positive outcomes (i.e., win/no loss). Average amplitudes of these waveforms at the time of the FRN (200 to 320 ms) were measured. Original frontal channels of the Biosemi montage were used in this analysis As the difference wave amplitude can be driven either by larger a negativity after losses or a larger positivity after wins, the absolute distance from the baseline as well as the direction (positive or negative) of the average difference wave amplitude is informative. Therefore, the data could not be reasonably reduced to only three midline channels by picking channels with maximal or minimal averaged amplitude.

Finally, a series of robust 2 x 2 ANOVAs were conducted on the data using MATLab 2010b custom functions. These measures are relatively new and thus are considered complementary to the SPSS analysis. This type of robust ANOVA uses original waveforms which were bootstrapped 1000 times and produces a statistic and a probability value for each time point of the waveform (based on Wilcox, 2005).

Currently, this analysis allows only comparison of 4 conditions at one location (i.e., one channel) or across all sites using Global Field Amplitude (GFA). A 2 (cue) x 2 (valence) robust ANOVA was conducted on the group data using GFA measures to identify the duration of significant main effects observed in the analysis of FRN peak amplitude and average amplitude of difference waves. Similar 2 x 2 robust ANOVAs were carried out on single subject data bootstrapping segments 1000 times to create a distribution for each participant.

Results

Validity Check

The pattern of responses on the *Post-Task* questionnaire in Experiment 2 was similar to that observed in Experiment 1 (Figure 2.9 and Table 1.8). Participants reported paying similar amount of attention to different cues on all tasks and found the cues to be least helpful in the No-Control condition. Unlike in Experiment 1, feedback in the No-Control condition was reported to be the least helpful and individuals reported paying the least amount of attention to it. The perceived frequency of wins and losses was similar across the tasks. Self-reported levels of tiredness/boredom were similar across all three levels of sense of control, but were slightly graded such that highest levels of tiredness were reported after the No-Control condition and lowest after Full-Control tasks.

The lowest levels of perceived control over the outcome and ability to predict the outcome were reported after the No-Control condition, as was expected.[4] Although the self-reported ability to predict the outcome was rated highest in the Full-Control tasks, it was only slightly higher than in the Some-Control condition. The perceived accuracy of

[4] The self-report data were collected using questions with a five-point rating scale. As this sample is relatively small, the data were not normally distributed, thus violating the assumptions of parametric tests.

predictions was graded in a similar manner, but the differences between average ratings were miniscule. Self-reported confidence in the predicted outcome was lower in the No-Control condition compared to the Some-Control and Full-Control. Furthermore, participants engaged in the use of strategy least frequently in the No-Control condition (n = 3; 25.0%; χ^2 (2) = 4.3, p = .012), while most reported having a strategy for the Some-Control condition (n = 8; 66.7%) and almost half had engaged in a strategy during the Full-Control condition (n = 5; 41.7%). These results are in line with the responses observed in Experiment 1 and suggest that the difference in perceived levels of sense of control over the outcome is highest between No- and Full-Control conditions and lowest between Some and Full-Control conditions.

Behavioural data

A 2 (cue) x 4 (outcome) repeated measures ANOVA was conducted to compare RTs in each version of sense of control tasks (Table 1.9). There were no effects of cue or valence in the Some or Full-Control conditions (see Table 1.10 for *M*s and *SD*s). The lack of outcome valence effects on the RT in the Full-Control condition does not replicate the findings in Experiment 1. Successful and failed trials were very similar in target duration, making it difficult to subjectively differentiate between win and loss trials during on-line performance on the task. This is supported by participants' self-report of ability to predict the outcome and accuracy of these predictions, which were very similar between the Full and Some-Control conditions. There was a main effect of valence in the No-Control condition such that participants were faster to respond on the potential win trials (win: M =276.44, SD = 54.30; no win: M = 272.30, SD = 57.59)

compared to potential loss trials (no loss: M = 285.63, SD = 60.23; loss: M = 294.43, SD = 62.69).[5]

[5] Post hoc tests using Bonferroni comparisons were used. Only the difference between win and loss outcomes (p=.040), no win and loss outcomes (p=.012) were significant. The difference between win/no win and no loss outcomes was marginally significant (p=.062).

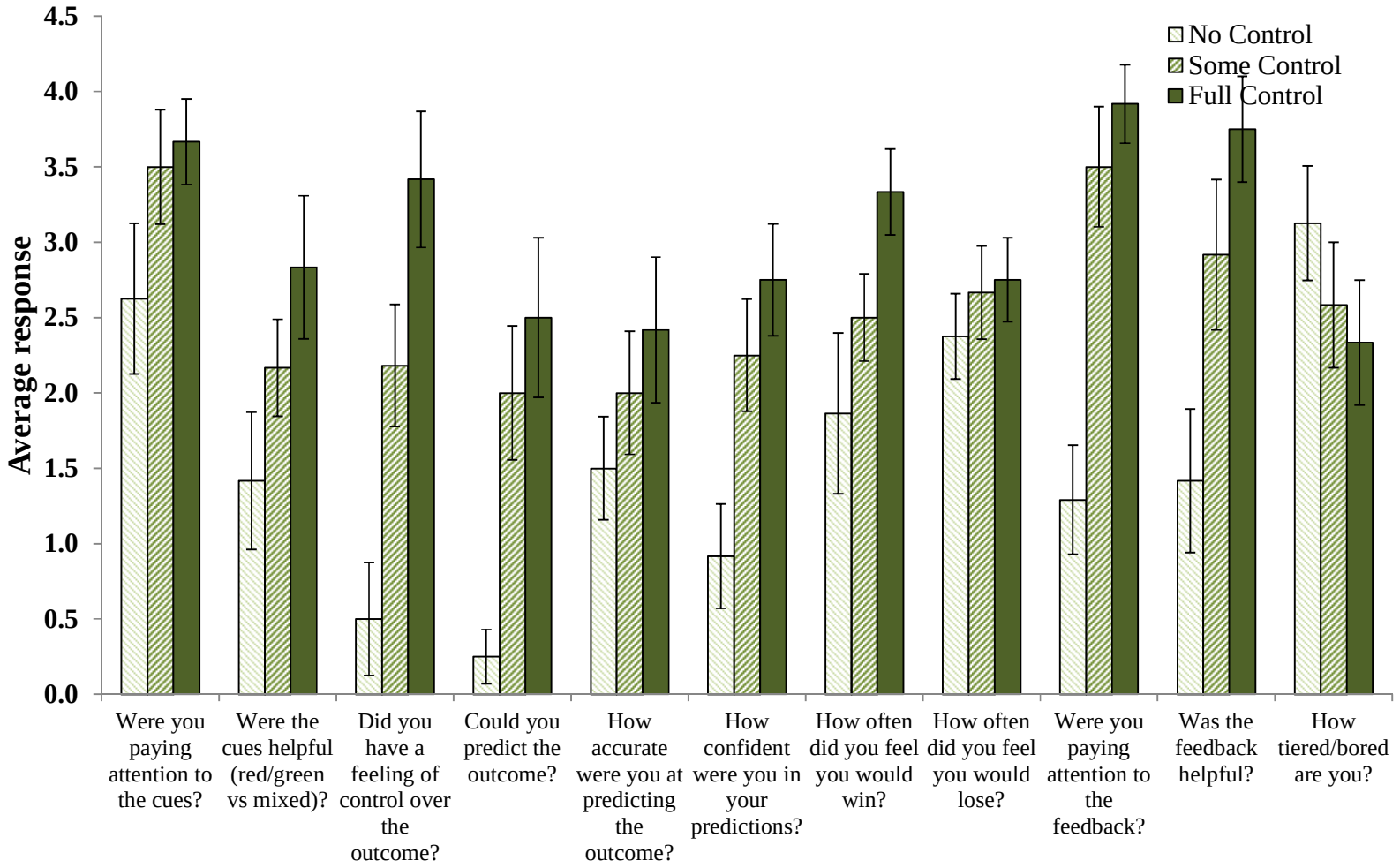

Figure 2.9. Graphical representation of means and standard errors of responses on the Post-Task questionnaire in Experiment 2

ERP Data

Peak measures.

As in Experiment 1, the FRN was defined as the most negative peak occurring between 200 and 320 ms after the presentation of feedback. The patterns observed in the waveform overlays partially supported the proposed hypotheses (see Figures 2.10 to 2.12; see Appendix 1.4 for overlays of waveforms with original Biosemi channels). More specifically it was hypothesised that (a) FRN valence effects would increase with increasing sense of control (i.e., negligible, if any, in the No-Control condition, larger in Some-Control and largest in Full-Control conditions), (b) presence of an informative cue would either attenuate these effects or have no effect of the FRN-valence effect, and (c) FRN-valence effect would be reversed in Full-Control condition with an informative cue. Similar to Experiment 1, the waveform overlay in the No-Control condition showed very small differentiation between win and loss outcomes at the time of the FRN. There were clear valence effects in the overlay of waveforms elicited in the Some-Control condition. Unexpectedly, the differences between win and loss outcomes in the Full-Control condition were relatively small and clear only at the frontal channels. Presence of cues seemed to have an effect on the waveforms following win outcomes in the Some-Control condition; this effect was more pronounced at frontal channels. In the Full-Control condition, loss outcomes were followed by a smaller FRN when the warning cue was informative. There was no evidence of the predicted interaction and reversal of the FRN-valence effect in the Full-Control condition.

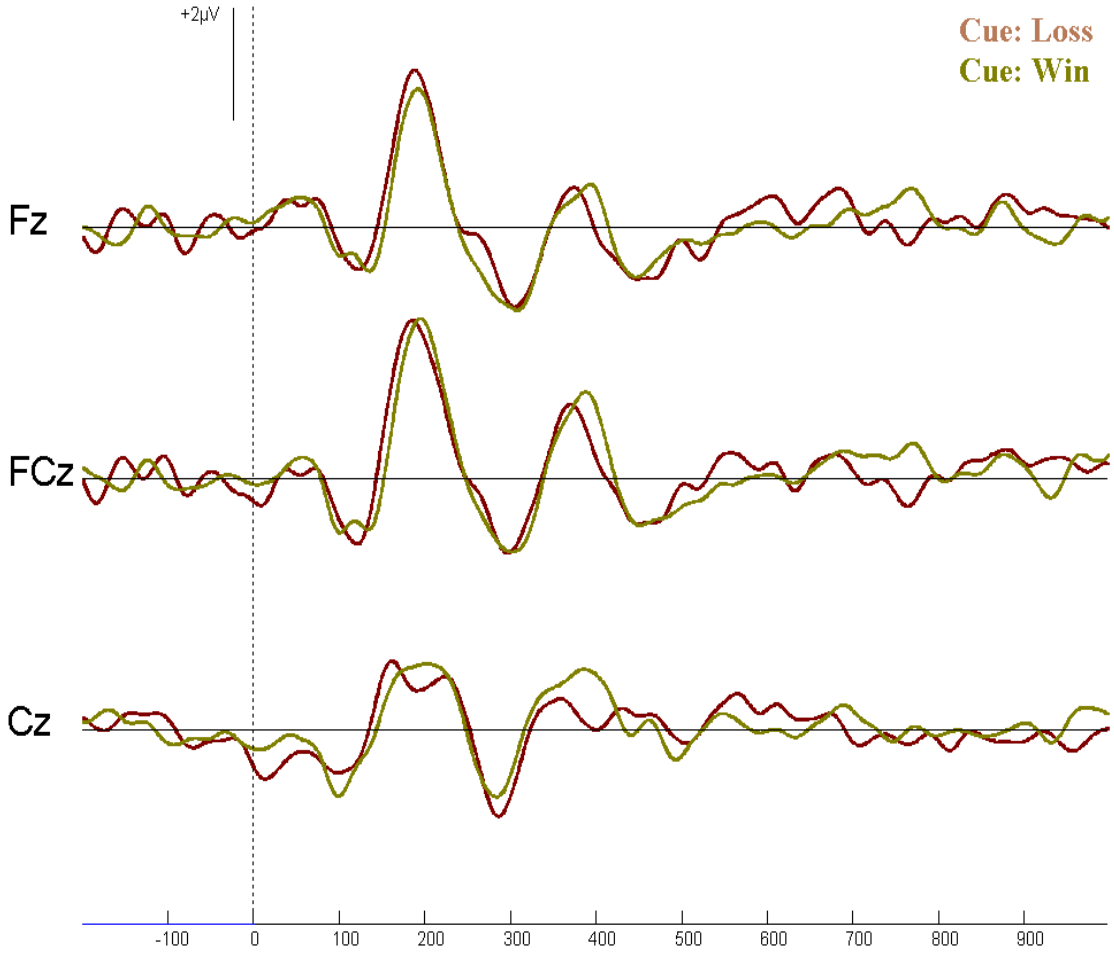

Figure 2.10. Averaged ERP waveforms for the two types of cues and two types of outcomes received in the No-Control versions of the task observed in Experiment 2

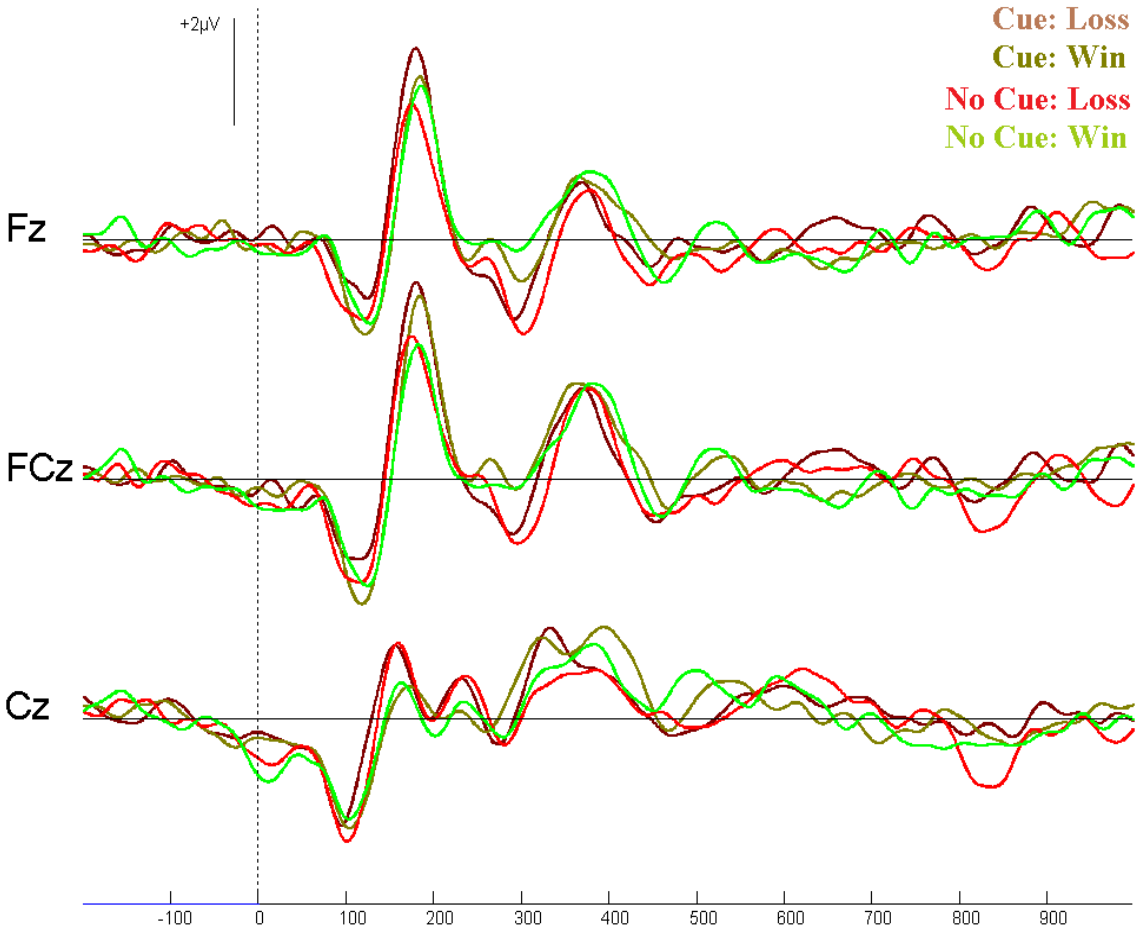

Figure 2.11. Averaged ERP waveforms for the two types of cues and two types of outcomes received in the Some-Control versions of the task observed in Experiment 2

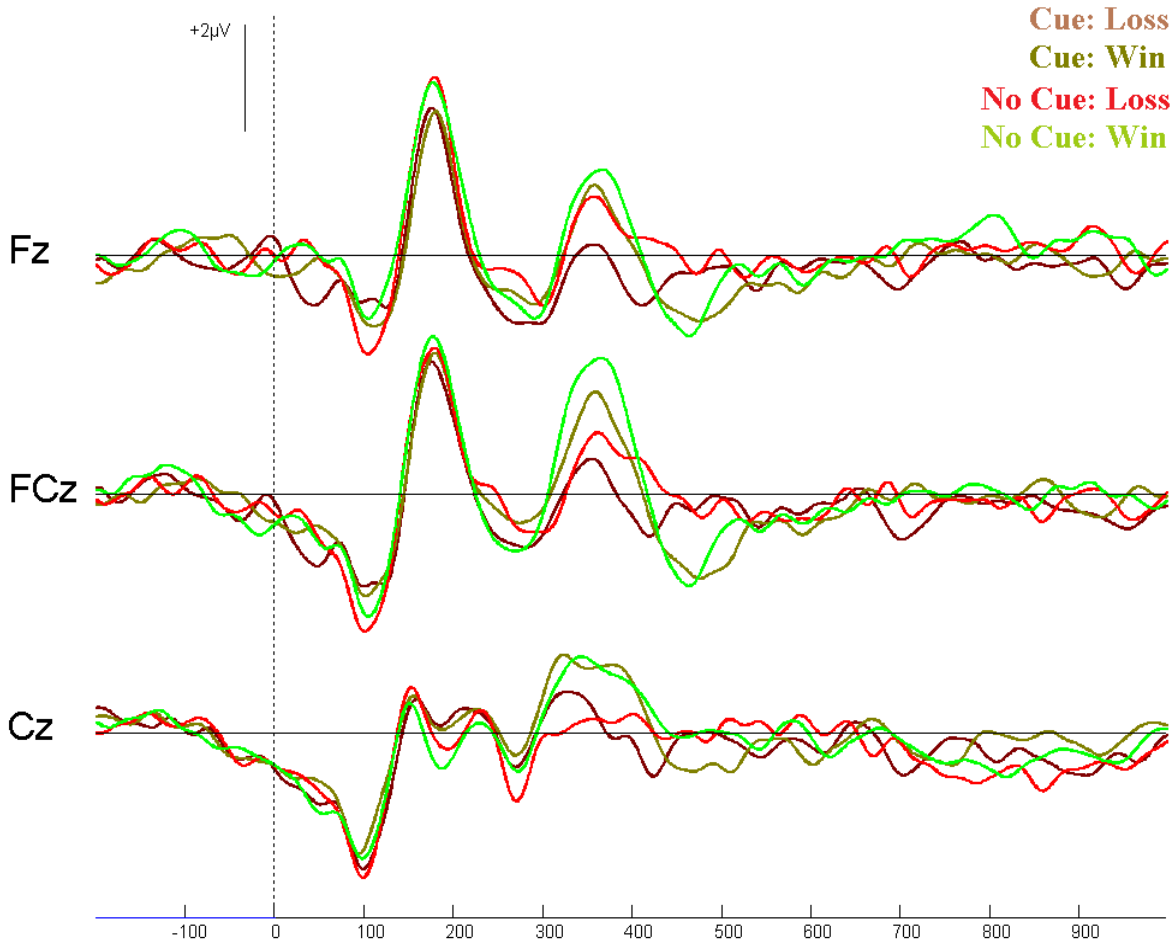

Figure 2.12. Averaged ERP waveforms for the two types of cues and two types of outcomes received in the Full-Control versions of the task observed in Experiment 2.

The initial analysis was carried out only using data from Some-Control and Full-Control conditions as there was no No Cue-No-Control condition, and the examination of cue effects would not have been possible. Effects of cue and sense of control on the FRN amplitude were examined using a 2 (cue) x 2 (sense of control) x 2 (valence) x 3 (channel) repeated measures ANOVA[6] (Table 1.11). There was a significant main effect of valence ($F(1,11) = 8.29$, $p = .015$, $p\eta^2 = .430$), such that FRN amplitude was larger

[6] Note: Because there was no NCue-No-Control condition in this data set, the analysis was first conducted using Full-Control and Some-Control conditions only.

following losses (M = -2.03, SD = 0.33) than wins (M = -1.53, SD = 0.33). An interaction between type of cue and sense of control was also observed ($F(1,11) = 6.54$, $p = .027$, $p\eta^2 = .373$). This interaction was superseded by a significant three-way interaction between sense of control, outcome valence and cue type ($F(2,22) = 9.08$, $p = .001$, $p\eta^2 = .452$). Contrary to expectation there was no reversal of the FRN valence effects in either of the Full-Control conditions. A follow-up repeated measures ANOVA was conducted to examine the three-way interaction by comparing FRN peak amplitude elicited by different levels of sense of control and valence in the presence or absence of the cue.

Informative cue condition. It was expected that presence of the cue would lead to the reversal of the FRN valence effect in the Full-Control condition. A 3 (FC, SC, NC) x 2 (loss vs win) x 3 (Fz, FCz and Cz) repeated measures ANOVA was conducted on the peak FRN amplitude observed after informative cues (Table 1.12). There were significant main effects of valence ($F(1,11) = 6.34$, $p = .029$, $p\eta^2 = .366$) and sense of control ($F(2,22) = 3.71$, $p = .041$, $p\eta^2 = .254$). Loss outcomes elicited a larger FRN amplitude (M = -2.07, SD = 0.35) than win outcomes (M = -1.59, SD = 0.37). If the sense of control manipulation worked as expected, FRN amplitude should be largest in Full-Control condition, followed by Some-Control and No-Control conditions. Contrary to these expectations, post hoc comparisons of the three levels of sense of control revealed no significant differences between the groups when a Bonferroni comparison was used. A more liberal LSD comparison showed a marginally significant ($p = .056$) difference between Some-Control and Full-Control conditions such that larger FRN amplitude was observed in the Full-Control condition (M = -2.09, SD = 0.37; Some-Control: M = -1.25, SD = 0.41). FRNs observed in the No-Control condition (M = -2.15, SD = 0.44) were

also larger than in Some-Control condition but this difference did not reach significance (p = .076). Although the effects of sense of control on FRN were not in the expected direction, the results suggest that the Some-Control condition was approached by participants in a different manner from other conditions. It should be noted that the sphericity assumption for the repeated measures ANOVA was almost violated (p = .059) and if the Greenhouse-Geisser correction is used, the main effect for sense-of-control becomes only marginally significant ($F(1,11) = 3.71$, p = .061, $p\eta^2$ = .252). Thus, the effect of sense of control in the informative cue conditions should be interpreted in caution.

Non-informative cue condition. It was hypothesized that in the absence of valence information in the cue, the FRN valence effects would be similar in all conditions (i.e., larger FRN following losses). A 2 (sense of control) x 2 (valence) x 3 (channel) repeated measures ANOVA conducted comparing FRN peaks in the non-informative cue condition revealed a three-way interaction between the variables ($F(2,22) = 8.40$, p = .005, $p\eta^2$ =.433; Figure 2.13; Table 1.13). As can be seen from the comparison of the means, overall the FRNs were smaller in the Full-Control condition compared to Some-Control condition. As no specific predictions regarding the site were made, a follow up analysis was conducted at every channel, in order to examine if sense of control effects were driven by FRN elicited by certain valence of the outcome (i.e., win or loss only).

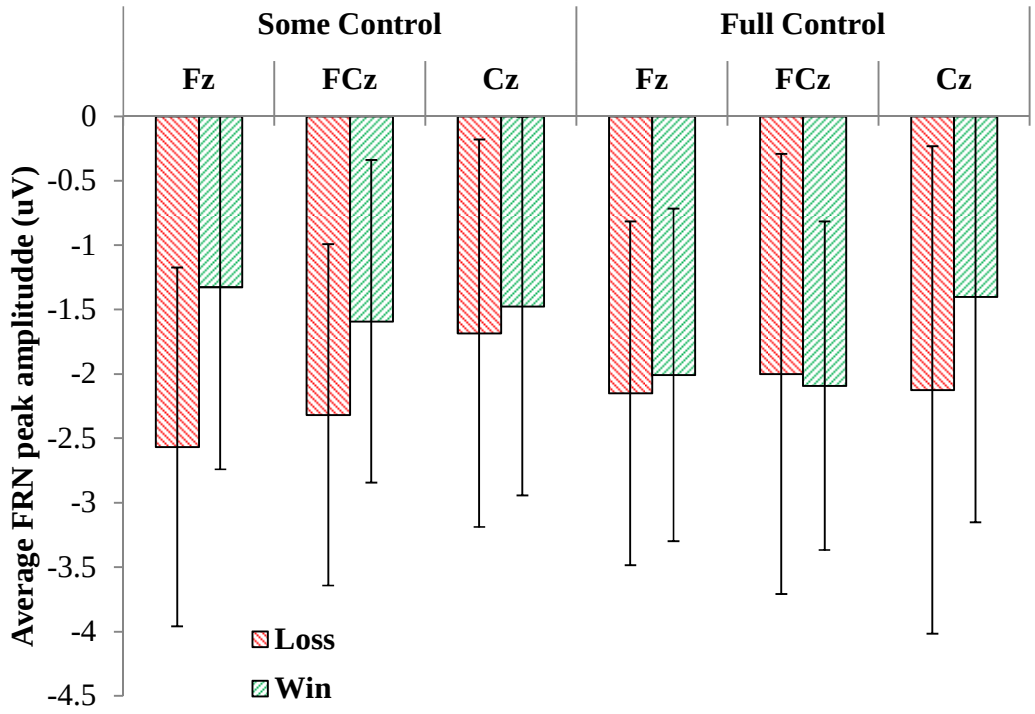

Figure 2.13. Graphical representation of the interaction between sense of control and channel observed in the No Cue conditions in Experiment 2.

In order to examine if sense of control had an effect on the FRN-valence effect a series of 2 (sense of control) x 2 (valence) repeated measures ANOVA was conducted for FRN peak amplitude at each channel (Table 1.14). As expected from the patterns observed in the means (Figure 2.13), there was a significant interaction between sense of control and valence at Fz ($F(1,11) = 5.74$, $p = .035$, $p\eta^2 = .34$). Two correlated t-tests were conducted to further understand this interaction. As expected from the patterns in the means, there was a significant valence effect in the Some-Control condition ($t(11)= 3.39$, $p = .006$) but no valence effect in the Full-Control condition ($t(11) = 0.40$, $p = .699$). Thus, the FRN valence effects were observed only in the Some-Control condition, such that losses elicited larger FRN compared to wins. No such difference was observed

in the Full-Control condition. The three three-way interaction among sense of control, valence and channel observed in the overall ANOVA was due to the presence of FRN-valence effects at Fz in Some-Control condition, but not in any other conditions.

Valence effects. The lack of FRN-valence effects in the no cue condition suggests that this task might not have worked as previously expected. In order to rule out this possibility a 2 (valence) x 3 (channel) ANOVA was conducted to examine if the FRN-valence effect was present or absent in the Full, Some and No-Control conditions (Table 1.15). In the Full-Control conditions, there was no significant valence effect when the cue was non-informative and a marginally significant effect of valence when the cue contained valence information (F (1,11) = 4.66, p = .054, $p\eta^2$ = .298). Losses elicited a slightly larger FRN peak amplitude (M = -2.37, SD = -0.31) compared to wins (M = -1.81, SD = 0.45). A similar analysis of FRN in the No-Control condition showed no significant effects or interactions of interest. A significant valence effect was observed in the Some-Control condition only when the cue was not informative regarding the type of trial (F (1,11) = 7.50, p = .019, $p\eta^2$ = .405; Cue condition: F (1,11) = 2.62, p = .134, $p\eta^2$ = .192). Thus, the analysis of peak FRN amplitude revealed that presence of valence information in the cue abolishes the valence effect observed in the Some-Control condition. Presence or absence of the cue had no significant effect in the Full-Control or No-Control conditions; however, this could be due to the relatively small FRN-valence effect observed in these conditions in the first place.

Summary. The current study failed to replicate the reversal of the FRN valence effect observed in Dzyundzyak (2010). A summary of the hypotheses and the obtained results can be seen in Table 1.16.

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Table 1.16. Summary of the hypothesised and obtained results of the FRN peak analysis in Experiment 2

	Hypothesised	Obtained
Valence (all conditions)	Loss > Win*	Loss > Win (only in Some-Control)
Sense of Control	No < Some < Full	No = Full < Some
Cue	No Cue > Cue	No Cue > Cue (only in Some-Control at Fz)
Interaction	Cue-Full-Control: Loss < Win	Cue-Full-Control: Loss = Win

*Note: effects are presented as absolute amplitude of the FRN (i.e., > means larger FRN)

FRN amplitude was expected to be attenuated with decreasing levels of perceived sense of control. This hypothesis was not supported, as FRNs were larger in the No-Control and Full-Control conditions compared to Some-Control condition. Furthermore, there were no consistent FRN valence effects in Full-Control and No-Control conditions suggesting that the tasks did not work as expected. The presence of a valenced cue was expected to attenuate the FRN or affect only the FRN following wins by eliciting reward positivity prior to presentation of feedback, thus, increasing the FRN valence effects. Presence of informative cue attenuated the FRN valence effects observed in the Some-Control condition, such that both FRNs elicited by wins and that elicited by losses were larger in the No Cue condition (loss: M = -2.19, SE = 0.37; win: M = -1.46, SE = 0.35) compared to Cue condition (loss: M = -1.48, SE = 0.45; win: M = -1.01, SE = 0.42).

However, the difference between wins and loss FRNs was significant only when the cue was non-informative. Thus, the effect of valenced cues on the FRN peak amplitude was partially supported.

Difference wave results.

According to Holroyd et al. (2008; 2011) any effects acting on the positivity elicited by rewards at the time of FRN can be missed if only FRN peak amplitude is analysed. It was predicted that effects of top-down and bottom-up factors will be dissociated in the reward positivity such that presence of an informative cue could attenuate the reward positivity at the time of the feedback, but manipulation of sense of control would have no effect. In order to examine effects of the cue and sense of control on the difference wave amplitude at the time of the FRN, a repeated measures 2 (cue) x 2 (sense of control) x 8 (channel) ANOVA was conducted (Table 1.17). A significant interaction between sense of control and channel was observed ($F(7,77) = 4.09$, $p = .045$, $p\eta^2 = .271$). In order to further investigate the source of significance for this interaction two repeated measures ANOVAs were conducted for the Some-Control and Full-Control conditions (Table 1.18). There were no significant main effects or interactions observed in the Full-Control condition. Only the main effect of channel was significant in the Some-Control condition ($F(7,77) = 6.92$, $p = .011$, $p\eta^2 = .386$), such that the average difference wave amplitude became more positive at more posterior channels. This finding is not surprising as effects of the P3 following the FRN (a positivity) are usually stronger at posterior sites.

The analysis conducted on the peak FRN amplitude revealed that that valence effects in the Some-Control condition were affected by the cue. Although no such interactions were observed in the overall ANOVA using a difference wave approach, in order to be

consistent with the literature and to further confirm this effect, a repeated measures ANOVA was conducted using the average amplitude of the difference waves obtained in the cue and no cue conditions (Figures 2.14 and 2.15; Table 1.19).

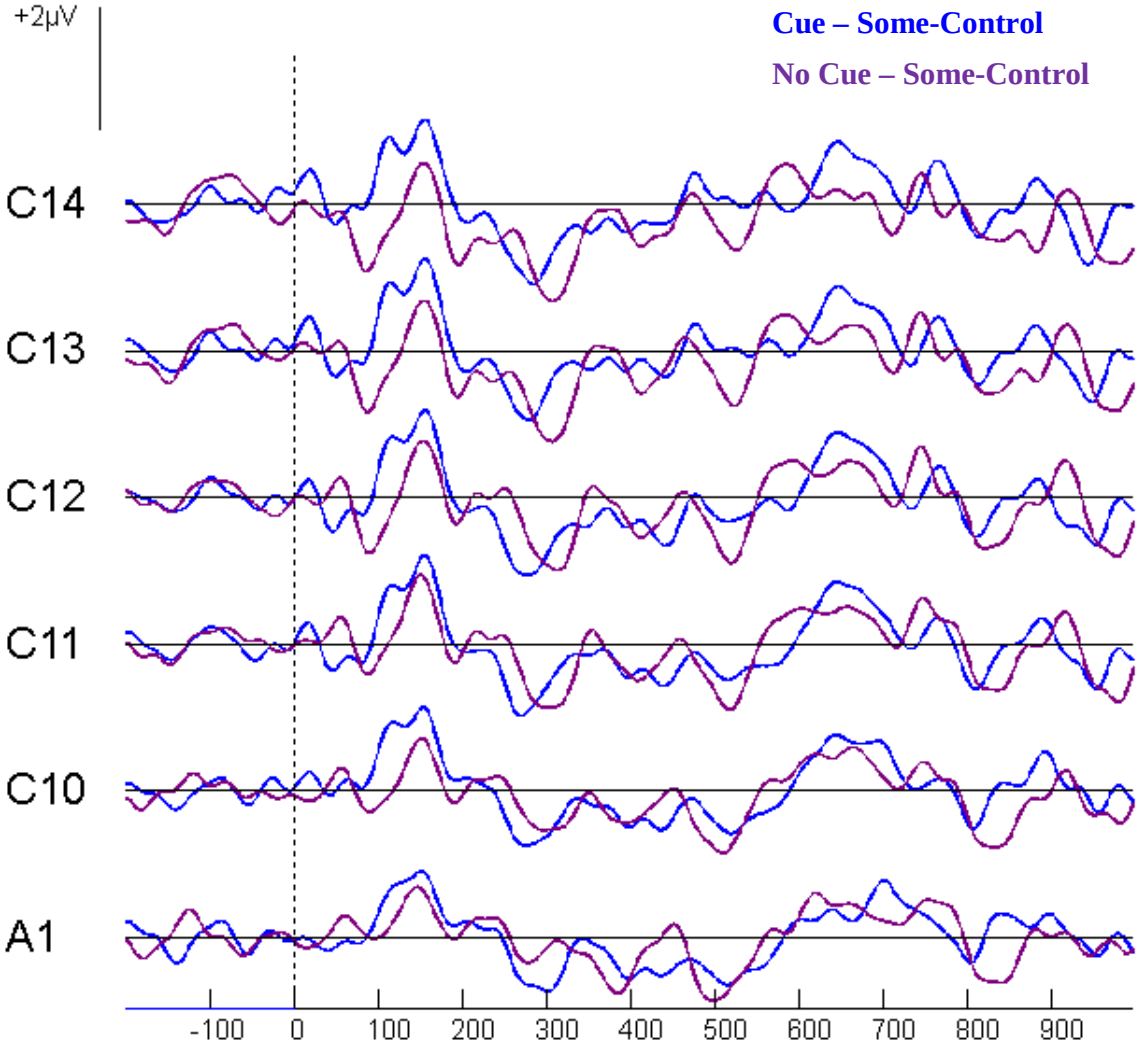

Figure 2.14. Averaged difference waves for the two types of cues received in the Some-Control condition in Experiment 2.

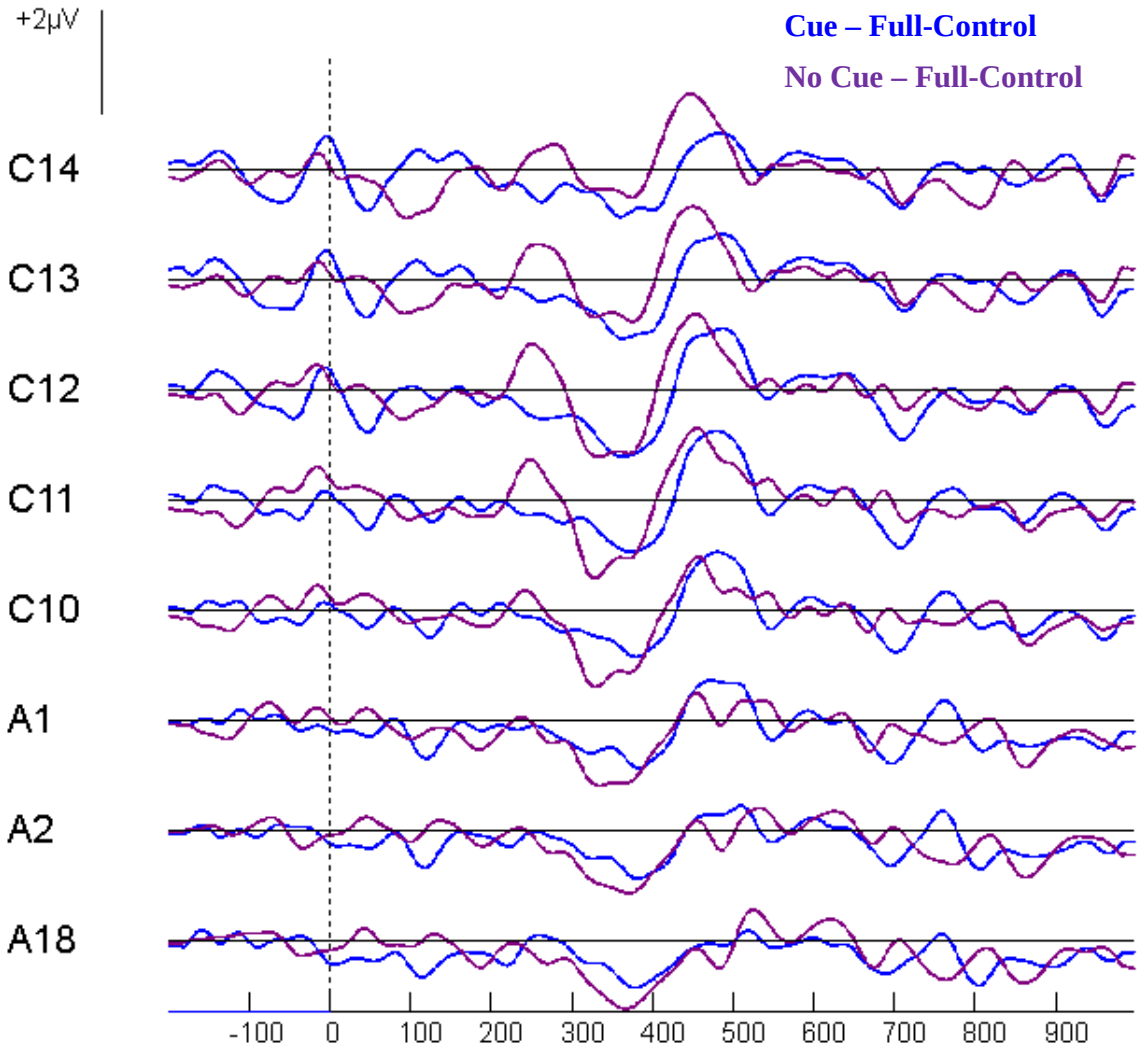

Figure 2.15. Averaged difference waves for the two types of cues received in the Full-Control condition in Experiment 2.

When valence information was present in the cue, there were no significant main effects or interactions. Thus, sense of control had no significant effect on the FRN-valence effect in the presence of the cues. A similar analysis was conducted on the No Cue conditions. There was a significant interaction between channel location and sense of control (F (7,77) = 5.16, p = .024, $p\eta^2$ =.319), such that the difference wave in the Full-Control condition was more positive than in the Some-Control condition at the

frontal channels, but more negative at the more central sites. As the effect can be divide into two parts – more anterior and more posterior than C10 – a follow up repeated measures ANOVA was conducted on either the four sites more frontal than C10 (i.e., C14, C13, C12 and C11) or three sites that were more central/posterior (A1, A2, A18). Two follow-up repeated measures ANOVAs were conducted to examine effects of sense of control (FC vs SC), cue (NC and C) and possible interactions on the average difference wave amplitude (Table 1.20).

Consistent with the analysis of the peak FRN amplitude, there were no significant main effects or interactions at the central/posterior sites. At the frontal sites, the effect of sense of control was significant (F (1,11) = 7.34, p = .020, $p\eta^2$ = .400), such that average difference wave amplitude at the time of FRN in the Full-Control condition was more positive (M = 0.12, SD = 0.28) compared to Some-Control condition (M = -0.64, SD = 0.20). This supports the hypothesis that the valence effect would be greater in the Full-Control condition.

Holroyd et al. (2008) proposed that these difference waves represent the effects of reward positivity at the time of the FRN. It was hypothesised that presence of an informative cue will either have no effect or attenuate the reward positivity at the time of the FRN. This hypothesis was partially supported, as the results of the difference waves' amplitude analysis conducted in the Cue and No Cue conditions suggest that presence of informative cues diminished the reward positivity at the time of the FRN in the Some-Control condition. The FRN following both wins and losses in the Cue/Some-Control condition was attenuated compared to the No Cue/Some-Control condition. However, given the absence of valence effects in the Some-Control/Cue conditions it is more likely

that more positive difference wave amplitude reflects smaller negativity elicited by outcomes in general rather than only due to presence of reward positivity per se.

Exploratory analysis using robust ANOVAs.

This hypothesis was further examined through the use of robust repeated measures ANOVAs on the group and single-subject GFA data. Comparison of Some-Control conditions were chosen based on the results of the peak FRN amplitude and difference waves analysis. A similar analysis was run on the data from individual subjects in order to examine the number of subjects showing this effect.

The robust ANOVA analysis conducted on the group GFA data showed no consistent effects of valence, cue or an interaction of the two factors (Figure 2.16), i.e., no significant effects of valence that lasted longer than 10 ms. Cue and interaction effects were not only as short, they were also later in the segment at 800 and 900 ms post-stimulus onset. As this result was inconsistent with the peak and difference wave analysis, a further investigation was conducted on single subject data.

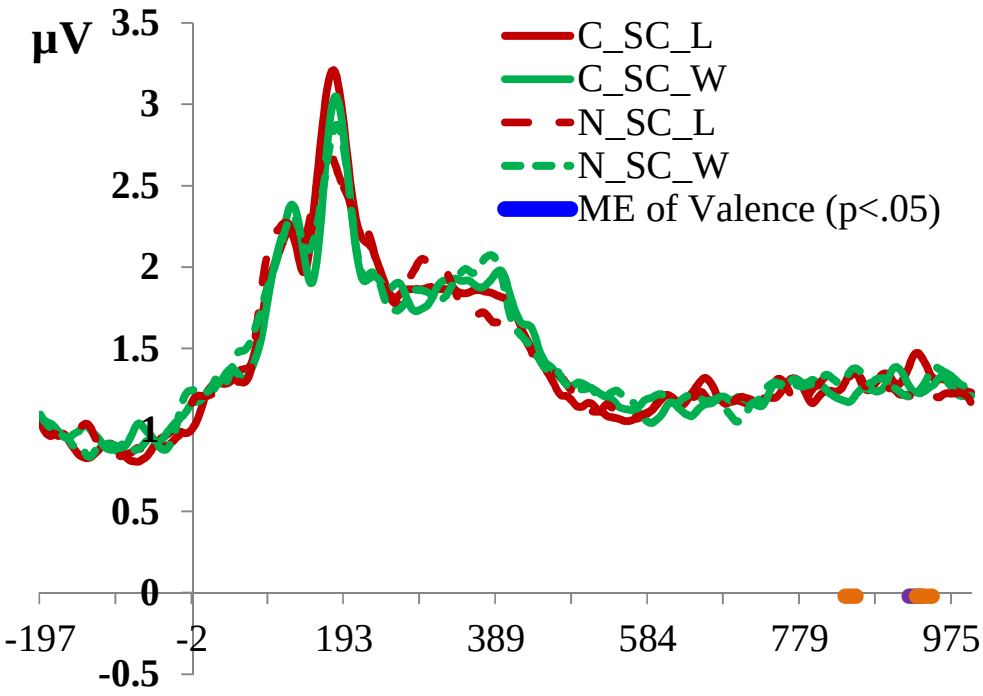

Figure 2.16. Overlay of the group global field amplitude (GFA) data and graphical representation of results of robust ANOVA analysis.

Robust ANOVAs were carried out to compare Cue-Some-Control and N-SC conditions in each subject. Patterns of significant values for the main effect of cue and valence were examined in order to identify individuals showing these effects (see Figure 2.17 for an example). A total of nine participants showed stable cue effects (75.0%; Figure 2.18) and eight subjects showed valence effects at the time of the FRN (66.7%; Table 1.21). There were no significant interaction effects between the type of cue and valence of the outcome, so no further investigation was conducted. It appears that the effects of the cue on the FRN, such that the FRN amplitude is attenuated in the presence of a valenced cue, are seen in majority of subjects. However, as no cue by valence interactions were observed, cue effects were not limited to either one of the valence conditions (i.e., loss or win).

(a) (b)

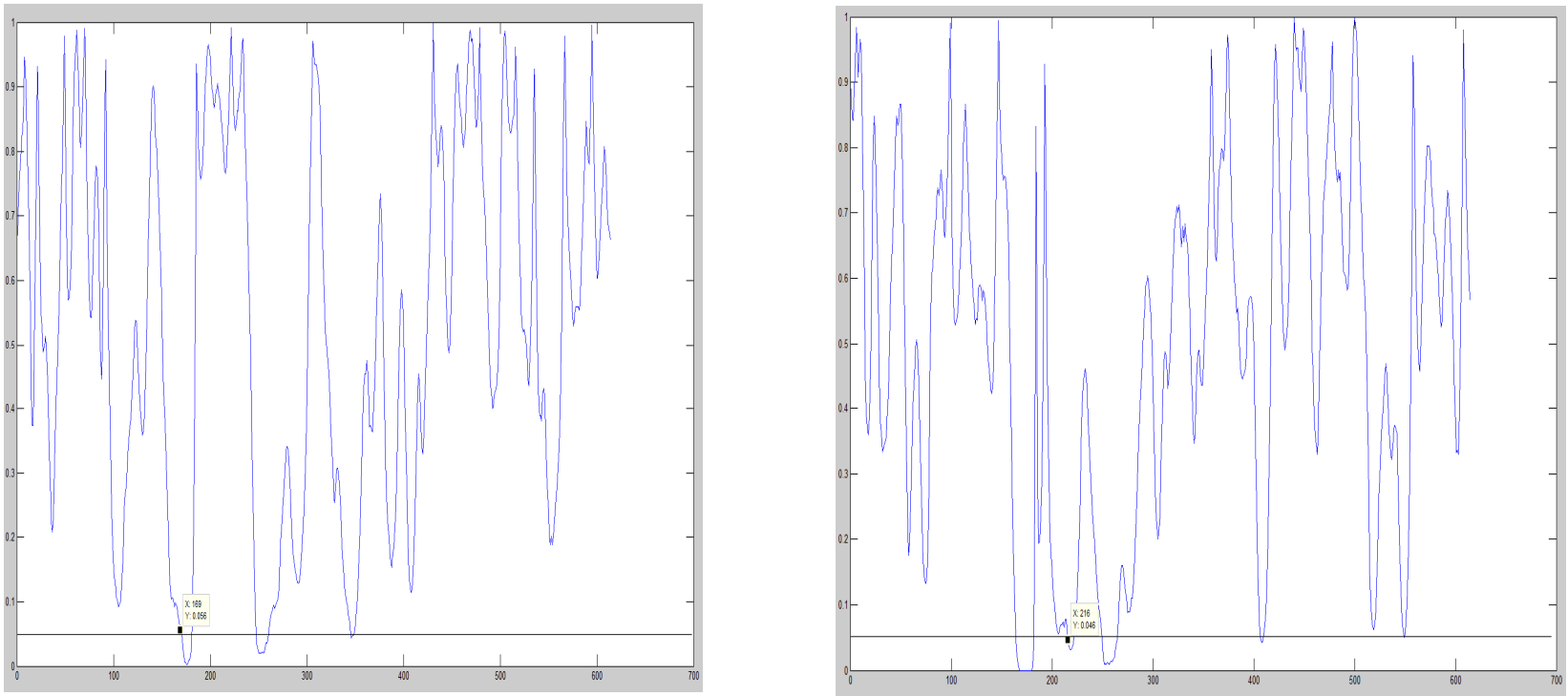

Figure 2.17. An example of significance values plot for the main effect of (a) cue and (b) valence for participant 14.

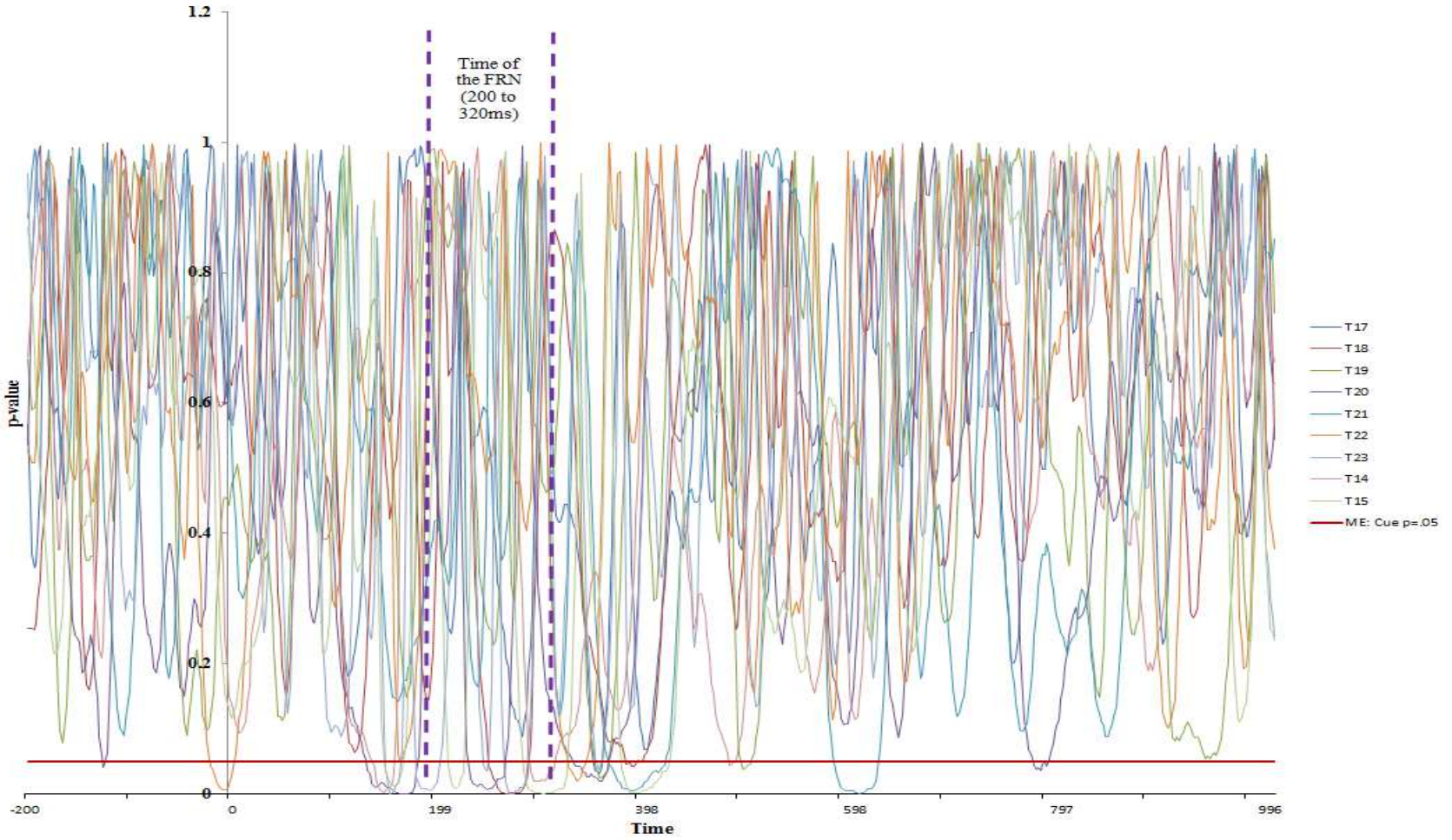

Figure 2.18. Overlay of significance value for cue effects across all subjects in the Some-Control condition.

Discussion

This study was conducted to examine the effects of cue and sense of control on the FRN and to replicate the reversal of the FRN-valence effect observed in Dzyundzyak (2010). Analysis of the activations at the time of the FRN showed that there was a significant interaction between levels of sense of control, type of cue and valence of the outcome. More specifically, the effects of valence of the outcome on the FRN were attenuated when an informative cue was present. However, these effects were observed only in the Some-Control condition. A follow up difference wave analysis showed that at a more frontal channels, the Some-Control condition elicited a larger negativity at the time of the FRN compared to the Full-Control condition. A follow up analysis of waveforms elicited in the Some-Control condition showed that the valence and cue effects on the FRN were observed in only 2/3 of the participants. The hypothesised reversal of the FRN-valence effect in the Full-Control condition was not observed in this study.

Sense of Control

The effects of a sense of control on the FRN amplitude were not consistent with the hypothesis that increased levels of control over the outcomes would lead to an increase in the FRN-valence effect due to greater investment at the time of outcome presentation. There were no significant valence effects in the No-Control condition, suggesting participants did not differentiate in the FRN between the outcomes or possibly were not engaged adequately at the time of outcome presentation. Furthermore, FRN-valence effects observed in the Full-Control condition were not consistently significant across

cue condition and were not in the direction hypothesised from the Dzyundzyak (2010) data. Only Some-Control tasks produced clear valence effects.

Thus, the results of the study should be interpreted with caution as lack of stable FRN-valence effects suggests that this experiment lacks power. In fact, although the study tested 12 participants, only 8 individuals showed stable valence effects in the Some-Control condition. It is possible that the length of testing time and similarity between the tasks affected participants' engagement in the tasks, as the Cue and No Cue conditions were presented sequentially for each level of sense of control. However, the presentations of sense of control conditions were counterbalanced and there was no consistent pattern of condition orders that explained lack of FRN-valence effects.

The established occurrence of the FRN-valence effect in the literature using a number of different tasks (e.g., time estimation, Miltner et al., 1997; gambling, Yeung & Sanfey, 2004; learning, Bellebaum, & Daum, 2008) suggests that the FRN sensitivity to valence reflects an automatic process. However, the results of this study led to the conclusion that this automatic effect is subject to modulation of arousal and engagement in the task. This is not surprising given the relatively late timing of this component as well as previous literature showing that lower investment in the outcome attenuates the sensitivity of the FRN to valence (Yeung et al., 2005).

Although the effects of sense of control manipulation were not in the expected direction, participants did perceive the levels manipulation of control to be different: If the sense of control manipulation had no effect on the FRN and subjects were not engaged in the tasks due to the length of testing session, the FRN effects in the Some-Control condition should have been attenuated when these tasks were at the end of the

session. In fact, participants who did not show FRN-valence effects performed these tasks at all stages of the experiment (i.e., first, second and last). Furthermore, of those who showed the FRN-valence effects, Some-Control tasks were presented at the end of the session an equal number of times as in the beginning or middle.

The reason for lack of the FRN-valence effect in the Full-Control and No-Control conditions could lie in the similarities between these tasks. Similar to the Full-Control condition, in the No-Control condition participants had to respond to the target cards within a longer but still limited period of time (700 ms). It is possible that participants viewed the Full-Control tasks as harder versions of the No-Control tasks, treating outcomes as not dependent on their responses, which in turn attenuated the FRN amplitude to the outcomes. However, this interpretation would be inconsistent with the self-reported feelings of control over the outcome.

Cue

Although the effects of sense of control on the FRN could not be interpreted due to the manipulation not working as well as expected, the effects of cue could still be examined. In the Some-Control condition, presence of the informative cues attenuated the FRN amplitude to both positive and negative outcomes. These findings are consistent with previous research that predictive cues elicit an FRN-like response that is similar to the FRN response to outcome valence (Deng et al., 2012). Furthermore, Holroyd et al (2011) showed that predictive cues elicited a positivity that affected the FRN amplitude at the time of outcome. The results of this study are consistent with these findings such that if presence of an informative cue elicited a response to positive

valence (i.e., potential wins), it would have affected the reward positivity at the time of the outcome, but not the response to losses.

Integration with Dzyundzyak (2010) data

It appears that the reversal of the FRN effect observed in Dzyundzyak (2010) was not due to the presence of informative cue or higher level of sense of control over the outcome. There were no other differences in the task structures and characteristics that could have influenced the FRN amplitude. Furthermore, two studies have used the MID task to examine the FRN sensitivity to valence and found that loss-FRN was larger than win-FRN (Santesso et al., 2012; Broyd et al., 2012). So it seems likely that the FRN effects observed were due to some difference in the structure of this version of the MID task compared to the versions used in the literature. In these studies the duration of the target was adjusted based on a practice period prior to the task or with a computerized algorithm during the task based on frequencies of rewards. More specifically, on the loss trials, the target was visible only for the 15^{th} percentile RT of the participant and on win trials on the 85^{th} (Santesso et al., 2012), a considerable difference in the paradigm from the dynamic adjustment method we used. A similar adjustment was made in the Broyd et al. (2012) study such that RTs were tracked throughout the task and target duration was adjusted after win responses to result in 66% win overall (Broyd et al., 2012). The version of the MID task used in Dzyundzyak (2010) adjusted target duration by a fixed period of time (+20/-10 ms) after every trial so the difficulty of the task varied throughout the task duration. If this is the case, the reversal of the FRN-valence effect could have been driven by the first blocks of the task where the difficulty was not uniform. The target was always presented for 280 ms at first, so the first few trials could

have been either a sequence of wins (if their average RTs were faster) or a series of losses (if their average RTs were slower), which could have set up expectations for the rest of the task. If this is the case, individuals would vary in their FRN responses depending on which outcome they were more set up to expect. This would explain why this effect was not replicated in other studies using the same paradigm. This hypothesis can further explain why there were no consistent valence effects observed in the Full-Control condition of this study. If loss outcomes were more unexpected than win outcomes for some individuals, a larger FRN would be observed following losses; however, if win outcomes were more unexpected then the FRN amplitude would reflect that by being more negative after wins. This variability in opposite directions would have been impossible to detect when working with group data. A more in-depth analysis of individual subject data could shed light on how many participants showed the valence effects in the expected direction (however, there are technical reasons at the moment preventing this analysis). Thus, further research is needed to determine whether the characteristic in the task structure of the MID used in Dzyundzyak (2010) is necessary to understand the reversal of the FRN-valence effect.

Summary

In summary, presence of cues attenuated the FRN-valence effects in a gambling task by eliciting a greater positivity at the time of the feedback presentation, as both wins and losses elicited a smaller FRN in the cue condition compared to No Cue trials. Thus, the hypothesis concerning effects of a valenced cue on the FRN was partially supported. Contrary to expectations, the manipulation of sense of control was not reflected in the FRN amplitude. More specifically, FRN amplitude in the No-Control and Full-Control

conditions was similar in size and larger than that observed in the Some-Control condition. This pattern of results cannot be explained by varying levels of sense of control, and suggests that there were unpredicted similarities between No-Control and Full-Control condition which in turn affected the FRN amplitude. A more in-depth analysis of the tasks is required in order to fully understand why the predicted effects were not observed. Finally, this study was conducted in order to replicate the reversal of the FRN valence effect observed in Dzyunzyak (2007). This reversal was not replicated, which could be due to low power or context of the task presentation (i.e., in conjunction with No-Control conditions rather than on its own). Nevertheless, the results of this study do not support the hypothesis that combination of valenced cue and high level of sense of control over the outcome produced the aforementioned reversal of the FRN-valence effect. Thus, it is likely that another characteristic of the MID task used in Dzyundzyak (2010) led to the observed reversal of the established FRN valence effect.

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STUDY 2: Effects of sense of control, expectation and gambling experience on the activity of the ACC: An ERP Study

The proposed model of FRN generation was tested in Study 2 by examining the influences of expectations and control over the outcome on the FRN amplitude. In contrast to Study 1 where sense of control objectively increased between conditions (i.e., ranging from watching the computer make a decision to outcomes depending on fast reaction times), in Study 2 the two tasks differed in *perceived* levels of control, as the outcomes were predetermined in both tasks and did not depend on participant's actual performance. In the gambling task, participants had to guess a correct 'door' for a reward (i.e., low control) as opposed to the second task where rewards were obtained after accurate estimation of time (i.e., higher control). As all of the outcomes were predetermined, any task effects (i.e., sense of control) on the FRN would occur due to a difference in cognitive set between the tasks (i.e., perceptions of control) and, thus, would be interpreted as support for top-down flow of information (i.e., from medial PFC). The second factor examined in this study was the difference between probability-based (bottom-up) and instruction-based (top-down) expectations. This was done through comparisons of FRNs elicited in a gambling paradigm, where participants were explicitly asked to make a prediction about the outcome, and a time-estimation task, where participants' expectations were modulated through instructions. The second goal of the study was to examine associations between gambling behaviour and the FRN. Two groups of participants were recruited for this study: individuals without and with evidence of problem gambling behaviour. Previous research has shown that severity of gambling behaviour as well as problem gambling status were associated with changes in

the functioning of the reward network (e.g., activity of the ventral stratum; Chase & Clark, 2010; Meidl, Peters & Büchel, 2012). There has been little research examining the differences in EEG measures between gamblers and non-gamblers; thus, this study was conducted to further understand whether (a) FRN can be used as a marker for problem gambling behaviour, and (b) problem gamblers respond to expectations and sense of control modulations in a fashion different from the non-gamblers given the changes in the activity of the reward system observed in problem gamblers.

Effects of expectations on the FRN

Previous research has shown that the individual's expectations about the outcome can influence the FRN amplitude (Bellebaum & Daum, 2008; Kobza et al., 2011; Liao et al, 2011). For example, a Time Estimation task, with easy and hard blocks, was used to show that when expectations are modulated by the frequency of the outcomes, unexpected/infrequent outcomes (e.g., loss in an easy block) elicited a larger FRN than expected/frequent outcomes (Holroyd & Krigloson, 2007). Similar results were found when expectations were manipulated through variable frequency of positive outcomes following certain cue-response key combinations (Pfabigani, Alexopoulos, Baue, & Sailer, 2011). The FRN amplitude was largest after unexpected negative outcomes (i.e., most unfavourable outcomes) which is consistent with the reinforcement learning theory, such that the FRN reflects the magnitude of prediction error based on both valence and expectedness of the outcome.

The nature of the FRN sensitivity to expectations has been further examined using PCA decomposition on the waveforms at the time of the FRN (Potts, Martin, Kamp, & Donchin, 2010). Participants' expectations were manipulated by associating trial cues

with different probabilities of winning. The study design also included a Flanker task allowing for examination of ERP responses during self-generated errors (i.e., ERN) as opposed to reward-prediction errors (i.e., FRN). The decomposition of the FRN and ERN showed that these components share a central generator and another more anterior generator that was active only at the time of the FRN. Thus, it appears that although ERN and FRN share a common generator, the FRN generation requires more complex activations. Baker and Holroyd (2011) expand on this idea by proposing that task-relevant events in general (e.g., errors) elicit an N2 component at the time of the FRN, which is shared with the ERN. Rewards on the other hand, also elicit a positivity that is absent on the non-reward trials and increases in size if reward was unexpected. Together the results of these studies can be interpreted as evidence for a more anterior generator active at the time of the FRN, which is responsible for reward positivity observed after gain outcomes. Thus, previous research suggests that effects of valence and expectation on the FRN are additive, such that prediction errors are calculated separately for events of positive and negative valence.

However, in most tasks the effects of expectations on the FRN are set up by using different probabilities of outcomes on different types of trials. Probabilities of outcomes are learned by exposure to different frequencies of outcomes of each valence, which are usually dependent on the type of trial, which leads to unequal frequencies of a reward and non-rewards/punishments for each type of trial. This approach complicates any attempt to dissociate the effects of valence and expectations as both of these stimulus characteristics are necessary for behavioural adjustment. In order to clarify the relative sensitivity of the ACC to expectedness and valence of a stimulus, a Time Estimation task

with three levels of outcomes (excellent, ok, bad) was used (Ferdinand, Mecklinger, & Gehring, 2012). The intermediate feedback (i.e., ok) occurred often and was expected but did not contain any valence information. The valenced outcomes (i.e., excellent and bad) occurred only 20% of the time and, thus, were unexpected. The valence effects observed were in the expected direction, such that FRN was larger after negative feedback than positive. Unexpected feedback was associated with larger FRN for both positive and negative outcomes, suggesting that the ACC activity is modulated by valence and expectedness of events separately and probably in an additive fashion. If a reward is unexpected it will elicit larger FRN amplitude than an expected reward; however, both of these FRNs will be smaller than those elicited by losses. It should be noted that these results are inconsistent with the effects of expectations on the reward positivity, which was proposed to increase for unexpected rewards and, thus, lead to a smaller FRN (i.e., FRN following unexpected wins would be more positive compared to expected wins; Baker & Holroyd, 2011). Thus, currently there is some debate in the literature with regard to effects of expectations on the FRN elicited by positive feedback.

More commonly, expectations on the task are set up by alerting participants to probabilities of a positive outcome on each trial. Hajcak, Moser, Holroyd and Simons (2007) examined the effects of expectations by giving participants four 'doors' to choose from and showing a cue on each trial informing them of the number of doors that contained a reward. Participants were asked to make explicit predictions about the outcome of the trial either prior to or post choice. Interestingly, expectations (i.e., accuracy of predictions) had no effect on the FRN amplitude elicited by feedback if the predictions were made prior to choosing a door. If the predictions were made after the

decision was made, unexpected events would elicit a larger FRN compared to expected outcomes. It appears as though the sensitivity of the FRN to expectation is dependent on the close temporal proximity of the prediction and the outcome or psychological investment in one's prediction (e.g., higher confidence). It is possible that effects of expectations are observed only when one's prediction is salient to the individual at the time of feedback presentation. In a previously described study, FRN valence effects were observed only if participants are given enough time to develop predictions (Bismark et al., 2013). Thus, in order for the effects of expectations to be observed at the time of the FRN, participants should be given enough time to develop these expectations but not long enough for the predictions to lose their salience at the time of the outcome.

In summary, the exact nature of the effects of expectation on the FRN still remains controversial as some studies report larger FRNs following all unexpected outcomes (Hajcak et al., 2007; Ferdinand et al., 2012), whereas others suggest smaller FRNs if unexpected outcomes are positively valenced (Baker & Holroyd, 2011). It has also been shown that the effects of expectation on the FRN are transient and can be seen only if that characteristic of the stimulus is salient at the time of feedback delivery (Hajcak et al., 2007; Bismark et al., 2013). Thus, the expectation effects on the FRN amplitude are dependent on the structure of the task used to elicit the FRN and more research is needed in order to clarify how this stimulus characteristic is coded by the ACC.

The effects of expectations are usually manipulated by varying the probability of the outcomes on certain trials using different types of cues to inform the participant of these probabilities. Previous research shows that the nAcb (i.e., basal ganglia) responds during learning of associations (e.g., cue-outcome pairing) by reacting to the presentation of the

cue in a similar fashion as to presentation of the outcomes (see Shultz, 2007, for review). The level of activation at the time of the outcome presentation is dependent on the strength of the cue-outcome association, and reflects the degree of violation of expectations. For example, in the 'doors' task used by Hajcak et al. (2007), participants were presented with a cue signifying the probability of positive outcome such that these cues predicted the frequency of rewards obtained. In this task, the degree of violation of expectation is presumed to be coded in subcortical structures as expectations are dependent on the cue-outcome associations. According to the proposed model of FRN generation (see Figure 3.1), if expectations are modulated by true cue-outcome associations (i.e., cues are predictive of the outcomes) any effects of expectedness of the stimulus on the FRN will reflect activation of the ACC driven by projections from the subcortical areas (i.e., bottom-up). However, if participants are only led to believe that these cue-outcome associations exist, while the frequency of positive outcomes is identical for each type of cue, any effect of expectation on the FRN will reflect top-down regulation of ACC activity. For example, expectations can be manipulated through instructions such that the task appears to have different types of trials (e.g., easy vs. hard) but in reality the probabilities of obtaining a positive outcome are equal across all types of trials. In this case, expectations are not based on objective stimulus characteristics but arise due to a different cognitive state at the time of outcome presentation. According to the proposed model of FRN generation, any effects of subjective (rather than objective) stimulus characteristics will be coded in the PFC and then projected down to modulate the activation of the ACC.

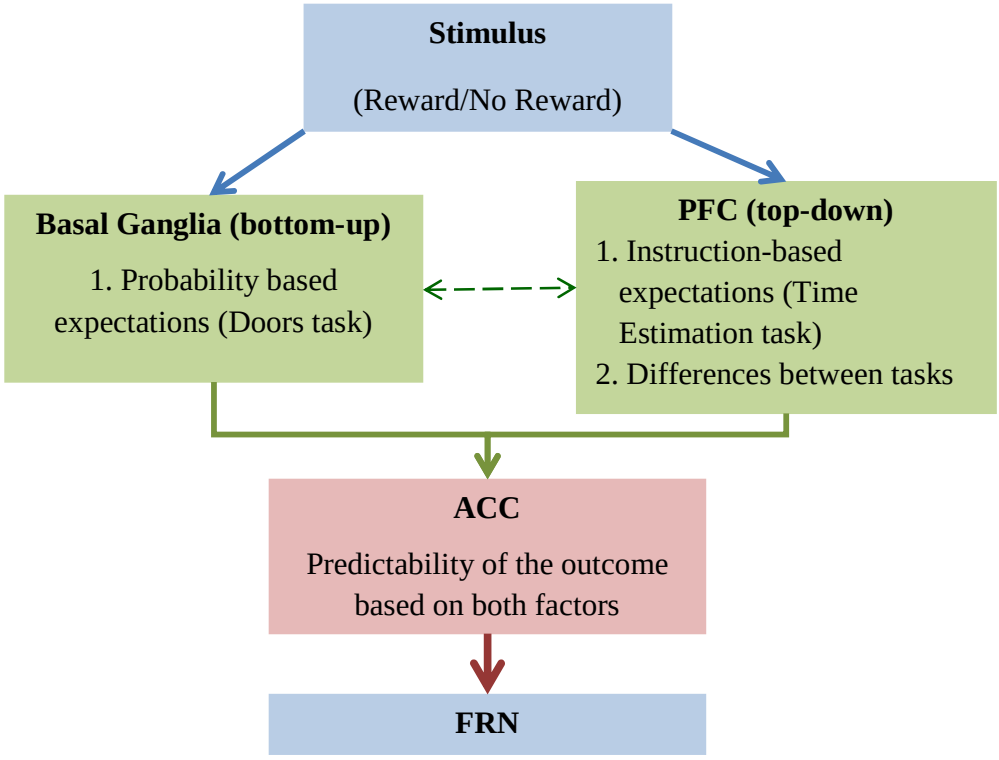

Figure 3.1. Graphical representation of the propose model and predicted pathways for the expectation and sense of control effects tested in Study 2.

These predictions were tested in Study 2 by comparing the effects of expectations in a gambling paradigm, where participants were asked to explicitly predict the outcome after exposure to a cue signifying probability of positive outcome, and a Time Estimation task, where expectations were manipulated by telling participants there are hard and easy trials. Outcomes in both tasks were predetermined, such that in the gambling task reward frequency was consistent with probabilistic cues, whereas in the Time Estimation task, the frequency of rewards following each cue was identical by the end of the task. It was hypothesized that expectations set up by instructions will modulate the FRN amplitude such that unexpected outcomes (e.g., win on a hard trial) will elicit a larger FRN compared to expected outcomes (e.g., win on an easy trial). This effect will be

interpreted as support for top-down control of the ACC at the time of the FRN. Any effects of expectation in the gambling task will be interpreted as evidence of bottom-up input to the ACC.

Gambling behaviour

The secondary goal of this study was to examine the effect of previous gambling behaviour on the FRN Problem gambling is one of few addictions that is purely behavioural and the changes in the central nervous system are not confounded with drug effects as is common with other addictions. There has been a great deal of research on the development of maladaptive gambling behaviour, environmental and personality risk-factors as well as heterogeneity of the samples (e.g., Ledgerwood & Petry, 2006; Myrseth, et al., 2010; Lorains, Cowlishaw, & Thomas, 2011; for a review on gamblers subtypes see Milosevic & Ledgerwood, 2010). Previous research has shown that there are a number of neurotransmitters, including dopamine, and structures in the reward network related to problem gambling behaviour (for a review see Potenza, 2008). . It has been consistently shown that dopamine is the neurotransmitter responsible for coding of rewarding information (Shultz, 2007). Increases in dopamine levels are associated with increased seeking of rewards, which sometimes lead to maladaptive behaviours such as overeating or excessive gambling (Dodd et al., 2005). In order to understand why problem gambling behaviour might influence FRN sensitivity to stimulus characteristics, we must first establish that the structures involved in FRN generation show altered activity in individuals with problem gambling behaviour. Recently more studies have been conducted examining the effect of maladaptive gambling behaviour on processing of reward-related information more generally.

Previous research has shown that administration of dopamine agonists to patients with lowered levels of dopamine (e.g., Parkinsons, Restless leg syndrome) can lead to manifestation of problem gambling behaviour and inability to control impulses (Dodd, et al., 2005; Tippmann-Peikert, et al., 2007). In participants with Parkinson's disease, increased capacity for dopamine synthesis in the ventral stratum was shown to be related to impulsive behaviour, particularly financial extravagance and irresponsibility (Lawrence, Brooks, & Whone, 2013). Additionally, patients exhibiting problem gambling behaviour were shown to have an increased release of dopamine in ventral stratum compared to their non-problem gambling counterparts (Steeves et al., 2009). If FRN is a marker for the *dopaminergic* signal relayed to the ACC, and problem gambling behaviour is associated with changes in the release or baseline levels of dopamine in the brain, then FRN should vary with variations in problem gambling status/severity. Similarly, if FRN reflects signalling within the reward network, any changes in the functioning of this network should be reflected in the FRN.

Further evidence for changes in activity of the reward network, more specifically the ventral stratum, in response to dopamine agonists (i.e., changes in dopamine levels) was provided by Abler et al. (2009), who measured BOLD responses of patients with restless leg syndrome (on and off medication) while they performed a version of monetary incentive delay task (i.e., similar to Full-Control condition described in Study 1). In this version rewards were delivered at different probabilities ranging from 0 to 100%. When patients were off medication (i.e., low levels of dopamine in the system) ventral stratum activity was highest for positive prediction errors (i.e., unlikely rewards) and lowest for negative prediction errors (i.e., unlikely losses). This pattern was reversed when

participants were on medication, and had higher levels of dopamine in the system. Thus, the results of this study further support the role of dopamine in prediction error signals and provide evidence that dopamine levels in the brain can drastically change the response to negative consequences. As none of the participants in the study developed problems with gambling behaviour, it still remains to be seen if these changes underlie development of problem gambling behaviour. However, increased dopamine release in ventral striatum has been shown to be associated with increased subjective ratings of excitement during Iowa Gambling Task in problem gamblers but not in controls (Linnet, et al., 2010) suggesting that activity of dopaminergic neurons in the reward network is altered in this population. Interestingly, this relationship was not significant in the non-gambling version of the task, where participants were instructed which card to pick (i.e., no dopamine release). Thus, this altered reactivity of the reward network is observed only in specific contexts. In summary, the evidence outlined above suggests that dopamine plays a role in maladaptive gambling behaviour, possibly by increasing arousal/excitement levels in gambling context and altering the response of ventral stratum to prediction errors. In other words, problem gambling behaviour is associated with altered reactivity of the reward network such that variations in baseline dopamine levels affect the prediction error signal in the basal ganglia, which in turn should be reflected in the FRN response. Similarly, any changes in the responsivity of the reward network (i.e., changes in the levels of activation of the structures within the network), should be reflected in the FRN. So it is important to establish that problem gambling is also associated with altered activation of various areas within the reward network.

For example, Chase and Clark (2010) showed evidence of changes in the ventral stratum activity in individuals with problem gambling behaviour by examining the activity of ventral striatum in response to reward information in a group of problem gamblers and compared it to healthy controls. A slot machine task was used to deliver three levels of outcomes: win, near-miss and miss. Wins occurred when the two 'wheels' displayed on the screen stopped at matching icons, whereas near-miss outcomes occurred when the second wheel stopped one position below or above a matching icon. Wins and near-misses elicited a similar response in the ventral striatum in all participants, suggesting that the reward network is sensitive to near-miss outcomes even though these outcomes do not lead to a reward. More importantly, severity of gambling problems was predictive of this activation such that more severe behaviour problems were associated with increased activity of the ventral striatum to near-misses. Gambling severity was not related to the activity of any other areas and did not predict activations following wins. Thus, maladaptive gambling behaviour is associated with altered responses of the subcortical areas to presentation of omitted rewards at the level of ventral striatum.[7]

Further evidence of altered reactivity of the reward network was provided by Meidl et al (2012), who conducted an fMRI study to examine the effects of delay and probabilistic discounting on the activations in the reward system (Meidl et al., 2012). Discounting is the decrease of subjective reward value that occurs either due to a delay in its delivery or due to low probability of the reward. The goal of the study was to examine if problem gambling status has a differential effect on the responsivity of the reward system to probabilities and delays of the rewards. The combination of delay and probabilistic discounting tasks used allowed the authors to calculate estimates of

[7] Note: Ventral striatum contains nAcb.

subjective reward value in each trial and examine the relationships between reward value and activity in the ventral striatum and orbitofrontal cortex. Individuals with problem gambling behaviour were less tolerant to delay of rewards (i.e., they discounted delayed rewards more steeply and were less sensitive to changes in subjective value of the stimulus due to changes in probability of the outcome compared to healthy controls. So, problem gambling status was associated with higher impulsivity (i.e., less willing to wait for rewards) and lower sensitivity to risks associated with reward attainment. The activation of the reward system reflected the behavioural results such that activations measured during the delay discounting task, but not in the probabilistic discounting task, were negatively correlated with gambling severity (i.e., impulsivity and not risk-taking was associated with changes in the activation levels). Furthermore, compared to healthy controls problem gamblers showed lower activations in ventral striatum and orbitofrontal cortex during the probabilistic task and higher activations during the discounting task, suggesting that these individuals are less sensitive to risks and more sensitive to delays of the rewards. Thus, we have further evidence that individuals engaged in maladaptive gambling behaviour show altered response of the reward network compared to healthy controls.

Furthermore, individuals with problem gambling behaviour were also shown to respond preferentially to certain types of rewards, which was reflected in the activation of the reward network (Sescousse et al., 2013). In their task, participants were first shown a cue which contained information regarding the type of upcoming reward (monetary vs. erotic), probability of the reward (25%, 50% or 75%) and its intensity (low or high). In order to have a chance at obtaining the reward, participants had to successfully perform a

visual discrimination task. Failure on the task automatically resulted in a loss, whereas successful performance led to presentation of either a reward (erotic image or picture of a safe with the amount won) or reward omission (scrambled picture). Behavioural data and activations during the anticipation period of the task suggested that pathological gamblers are less motivated by erotic rewards than monetary incentives. Furthermore, subjective ratings of rewards were correlated with activity of ventral striatum such that healthy controls showed increased activations with higher reward values for all types of rewards, whereas in gamblers such relationship was observed only for monetary rewards. Thus, pathological gamblers seem to be driven more by monetary rewards, and this preference is reflected in the activity of the basal ganglia. Furthermore, gamblers also recruited orbitofrontal cortex during processing of monetary and erotic rewards, but healthy controls did so only for erotic rewards. Thus, gamblers were shown to have greater recruitment of the subcortical and cortical areas within the reward network in response to monetary rewards.

Similar results were obtained by van Holst et al (2012) who examined activations of the striatum (ventral and dorsal; i.e., subcortical) and orbitofrontal cortex (i.e., cortical) in gamblers and healthy controls during a gambling paradigm where magnitude and probability of the reward were manipulated. Compared to controls, problem gamblers showed higher activity of the striatum to stimuli with larger magnitude and higher activity of both the striatum and orbitofrontal cortex to gains. There were no group differences for loss trials, suggesting that gambling is associated with altered response to rewards but not punishments. Severity of gambling was not associated with activation of any of these areas, but did relate inversely to amygdala activity such that individuals with

higher severity scores showed lower amygdala activity during gain trials. The results of this study suggest that problem gamblers process gain information differently from controls, both in the reward and emotion/motivation (i.e., amygdala) areas.

Gambling behaviour and ERP research.

In summary, previous research shows that maladaptive gambling behaviour is associated with changes in dopamine availability within the reward network and altered reactivity of this network. More specifically, individuals with problem gambling behaviour have differential recruitment of reward-related structures at the time of reward delivery and anticipation compared to healthy controls. These activations relate to gambling severity, subjective value and type of the reward. According to the reinforcement learning theory, the FRN reflects the dopaminergic signal from the subcortical areas of the reward network. Furthermore, the model of FRN generation proposed in this dissertation states that this prediction error signal is also modulated by cortical areas (i.e., medial PFC). If this is indeed the case, altered activations of dopaminergic subcortical and medial prefrontal areas suggest that effects of altered reward processing observed in problem gamblers can also be reflected in the EEG measures of feedback processing. To date, there have been only a few studies examining the variability in the FRN in response to gambling status.

Oberg, Christine and Tata (2011) have shown that healthy controls and individuals with problem gambling behaviour differ in their FRN response during a computerized version of the Iowa Gambling Task. On each trial, participants were asked to choose the size of the bet (large vs. small) and then were shown the outcome of the trial (win vs. loss). In gamblers outcome valence was differentiated in the ERP waveforms earlier than

in healthy controls. This differentiation was localized to the medial frontal cortex and appeared to be an FRN with an earlier latency. The amplitude of this early FRN was significantly correlated with gambling severity such that FRNs became smaller (i.e., more positive) as severity of gambling increased. Thus, as was expected from the results of fMRI studies, previous history of gambling behaviour has been shown to modulate the activity of reward network which was reflected in the FRN.

Further examination of the FRN sensitivity to gambling experiences was compared across healthy controls and individuals with problem gambling behaviour (Torres et al., 2013). Successful task performance depended on learning of the association between probability of a reward and response as well as ability to adapt when these contingencies suddenly changed. Problem gamblers showed an attenuated FRN response to feedback compared to healthy controls. These results are consistent with fMRI studies showing altered activation of the reward network in individuals with problem gambling behaviour (Chase and Clark, 2010; Meidl et al., 2012), which would be expected to lead to altered FRN response compared to healthy controls.

To date, there is only one other study comparing FRN response in healthy controls and problem gamblers (Kreussel, et al., 2013). A modified version of blackjack (the goal of which is to pick cards to approach as closely as possible but not exceed a total of 21) was used to elicit FRN response to three types of feedback: win, near loss and full loss. Full-loss trials were defined as trials where the final sum of the drawn cards was between 24 and 26, whereas on the near loss trials the sum was 22 or 23. At the time of the FRN, healthy controls showed a larger response following near-loss trials than on full-loss ones suggesting that near losses were viewed as more negative compared to full losses.

Interestingly, this effect was not observed in gamblers, who seemed to not differentiate between the gradations of negative outcomes. This finding is inconsistent with Chase and Clark's (2010) results who showed that near-miss outcomes led to greater activation of ventral stratum in problem gamblers; however, the nature of the relationship between activation of the ventral stratum and the size of the FRN has not been well-established. The dopaminergic signal can have either an excitatory or inhibitory effect on the receiving area, depending on the type of receptor that it binds to (Missale et al., 1998). Thus, activity in ventral striatum can lead to either an increased or decreased activation of the ACC and a larger/smaller FRN response. Nevertheless, both studies show that problem gamblers differ from healthy control in the recruitment of the reward network in response to omission of rewards.

In summary, previous research showed that individuals with problem gambling behaviour show altered activity in the structures associated with reward processing. Similar effects were observed using EEG measures, such that FRN observed in gamblers was not as sensitive to the distinctions between the gradations of outcomes as FRN observed in healthy controls. Thus, the altered response of the reward network observed in previously described fMRI studies is reflected in the FRN amplitude and latency. Unfortunately, there are only a few studies examining the FRN response in problem gamblers and the results of these studies were inconsistent (e.g., earlier latency of the FRN in gamblers found by Oberg et al., 2011, has not been reported in other studies). As there is no research examining the effects of expectations and sense of control on the FRN sensitivity in problem gamblers, no specific hypothesis about the direction of the

differences between the groups were made. However, it is expected that gamblers will show a differentiated FRN response (attenuated or enhanced) compared to non-gamblers.

Hypotheses

This study was constructed to test the proposed model of FRN generation by examining the effects of sense of control and expectations on the FRN in a sample of non-gamblers/recreational gamblers and individuals with various levels of problem gambling behaviour. The tasks were designed to differ on the amount of perceived control over the outcome; participants were expected to report higher ability to predict outcomes and higher confidence in their predictions after the Time Estimation task compared to the Doors task. Higher levels of control over the outcome were expected to either increase the FRN amplitude in general or increase the size of the FRN-valence effect due to greater investment in the outcomes in the Time Estimation task compared to the Doors task.

Previous research has also shown that problem gamblers often hold cognitive distortions regarding their ability to control outcomes. For example, compared to recreational gamblers, problem gamblers report significantly higher levels of beliefs in their ability to control outcomes in gambling situations through the use of strategies or skill, beliefs in "winning streaks" or near-wins signifying increased chances of winning, higher levels of impaired control over own gambling habit, and memory bias (i.e., remembering wins and discounting losses; Johansson, et al, 2009). Some of these effects were replicated in another sample of recreational gamblers, who reported higher levels of 'fate control' belief (i.e., belief that life events are predetermined and one has No-Control over the outcomes), which was positively correlated with gambling frequency (Tang &

Wu, 2010). Thus, this relationship was mediated by positive expectations (i.e., gambling leads to positive outcomes) and perception of lack of control over one's gambling habits. Thus, individuals who engage in gambling behaviour (recreationally or pathologically) show cognitive distortions that lead to perception of increased control over the outcome. As the two tasks used in this study were expected to be different in perceived levels of sense of control over the outcome (i.e., low in the Doors task and high in the Time Estimation task), it is possible that gamblers would not differentiate their responses in the two tasks on this variable. Thus, an interaction is expected between gambling status and sense of control, such that any effects of sense of control on the FRN would be observed only in the non-gambling sample.

The hypothesis based on the proposed model was that complex cognitive constructs that affect the participant's cognitive state at the time of the task also influence the ACC activity and in turn the FRN. These influences are proposed to occur through frontal projections to the ACC. As in Study 1, any influences of the "sense of control" on the FRN-valence effects would be interpreted as evidence for the top-down modulation of the FRN.

Effects of expectedness of the outcome on the FRN were also examined in this study. In the Doors task, participants were asked to predict the outcome prior to the presentation of feedback. The trials were then divided into expected/unexpected wins and losses. In the Time Estimation task, the expectedness of the outcome was manipulated through instructions such that participants were under the impression that the task contained easy and hard trials. Participants were informed of the difficulty of the trial with a cue prior to the time estimation period. The trials were divided into expected wins (easy trial wins),

expected losses (hard trial losses), unexpected wins (hard trial wins) and unexpected losses (easy trial losses). The task was designed to have predetermined outcomes which were independent of participants' responses and resulted in equal frequency of each type of outcome by the end of the task.

Effects of expectation.

Any effects of expectations observed in the gambling task are interpreted as evidence for bottom-up modulation of ACC activity, as the expectations were manipulated through the probability and frequency of the outcomes. In the Time Estimation task, expectations were manipulated through instructions and, thus, expectation effects on the FRN were interpreted as evidence for top-down modulation of the ACC activity.

(a) Previous research has shown that FRNs following unexpected outcomes are larger in amplitude compared to those following expected outcomes as long as these expectations are salient to the individual at the time of outcome presentation (e.g., Holroyd & Krigloson, 2007; Pfabigani, et al., 2011; Ferdinand et al., 2012). Thus, it was hypothesized that unexpected outcomes would elicit larger FRNs compared to expected ones.

(b) Additionally, if the reward positivity increases for trials with unexpected outcomes as was suggested by Baker and Holroyd (2011), it is possible that unexpected wins would elicit smallest FRN amplitude (i.e., most positive).

(c) Currently, there is no previous literature examining the effects of expectations on the FRN where probability of the outcomes was not manipulated. Thus, a sub-goal of this study was to determine whether the manipulation in the Time Estimation task would affect the FRN sensitivity to the expectedness of the

outcome in a manner similar to that of the Doors task, i.e., unexpected outcomes should lead to larger FRN amplitude or elicit larger reward positivity.

(d) As there is no research to date regarding effects of expectations (whether top-down or bottom-up) on the FRN in problem gamblers, no specific hypothesis was made for this group. Thus, these analyses are exploratory.

Sense of Control.

In contrast to Study 1, only the perception of sense of control over the outcome was manipulated in this study as the outcomes on all tasks were predetermined and were independent from participants' performance. Thus, any effects of sense of control (i.e., task effects) on the FRN are interpreted as evidence of top-down modulation of ACC activity. An interaction between sense of control and gambling status is expected such that:

(a) Increased perception of sense of control is expected to increase the FRN valence effect (i.e., larger difference between win and loss FRNs)

(b) only in the non-problem gambling group.

Group differences.

Relationships between several individual difference measures (i.e., HEXACO and Locus of Control) and FRN elicited in each task were examined. Any potential differences between the two samples on these measures were also investigated. Due to the relatively small sample size, these analyses were considered exploratory. Finally, effects of frequency of gambling behaviour on the FRN were also investigated. Previous research had shown a relationship between activation of the reward network and severity of gambling (Chase & Clark, 2010; Meidl et al., 2012). Based on the hypothesized

dopaminergic nature of the FRN, it is expected that increased frequency of gambling would be related to the FRN amplitude or latency.

(a) Problem gamblers are expected to produce similar patterns of FRN activity across both tasks, whereas for non-problem gamblers, FRN sensitivity should change with increasing perceptions of control over the outcome as outlined above.

(b) Based on the results of Oberg et al. (2011) problem gamblers are expected to differentiate between the valence of the outcomes earlier than non-problem gamblers (i.e., earlier FRN peak latency).

(c) Torres et al. (2013) suggest that problem gambling might be associated with an overall attenuated FRN response, so it is hypothesised that problem gamblers will have smaller FRNs for all types of outcomes compared to the control group (i.e., non-problem gamblers).

(d) An interaction between self-report ratings of control and gambling status is expected, such that only individuals not at-risk for problem gambling will rate their perceived control over the outcomes higher in the Time Estimation task compared to the Doors task. The Locus of Control measure was also included to examine if there are any group differences in the belief that one's actions affect (internal) or do not affect (external) outcomes. It is expected that problem gamblers will report higher levels of external locus of control.

(e) Previous research has shown that individuals at high risk for problem gambling score significantly lower than at-risk and low-risk gamblers on measures of Emotionality, Honesty-Humility and Conscientiousness (Twigger, 2010).

Personality factors were examined in this study with the same measure (HEXACO) in order to replicate these findings. Furthermore, if such differences are found, it is expected that measures of FRN will mediate this relationship.

Methods

Participants

A total of 46 adult participants from the Niagara area community and Brock University campus were recruited for the study through an online ad (posted at www.kijiji.ca). Due to the nature of one of the tasks (doors task, see below) three participants did not have enough trials in the expected loss and unexpected win conditions and their data were removed from the analysis. Additionally two participants were found to be consistent outliers (±3SD) on several ERP measures and were also excluded from the analysis.

The remaining sample of 41 participants contained 28 males (68.3%) and, on average, participants were 30.61 years old (*SD*=9.52; range: 19 to 50). The majority reported being right handed (*N*=34; 82.9%), White/Caucasian (*N*=33; 80.5%), with no history of neurological disorders. Most participants had some college or university education (*N*=18; 43.9%) or competed high school (*N*=9; 22.0%). Upon recruitment participants were screened on their gambling habits and risk for PG. The final sample consisted of 10 non-gamblers (i.e., did not engage in any gambling behaviour in the past year), 12 recreational gamblers (i.e., engaged in gambling behaviour in the past year but were not at risk for PG), five low risk PG, six moderate risk PG and eight high risk PG. The demographic information for each group is presented in Table 2.1. In order to

increase statistical power the sample was divided into no-risk PG (*N*=22) and at-risk for PG (*N*=19) groups.

Materials

Questionnaires.

The questionnaire package is attached in Appendix 2.1. Participants were screened for PG behaviour using the *Problem Gambling Severity Index* (PGSI; Ferris & Wynne, 2001). This measure asks participants to rate frequency of certain behaviours on a scale ranging from zero (never) to three (almost always). The questions assess frequency (e.g., Have you bet more than you could really afford to lose?) and consequences (e.g., Has your gambling caused any financial problems for you or your household?) of maladaptive behaviour using nine questions. More detailed information regarding gambling behaviour, such as frequency and number of different gambling activities engaged in, was assessed using the *Gambling Behaviour Questionnaire*. The GBQ asks participants to report how often in the past year (ranging from *never* = 0 to *daily* = 7) have they engaged in a variety of gambling activities (e.g., played instant-win or scratch cards, bet on TV show outcomes). Frequency of gambling behaviour was measured as an overall score on the questionnaire, regardless of the number of different activities reported.

Demographic information, such as age, sex and handedness was also collected. Handedness information was measured using a modified version of the *Handedness Questionnaire* (Oldfeild, 1971), where participants were asked to rate on a 5-point scale

which hand they would use to carry out specified everyday activities (e.g., Which hand is used to throw a ball?).[8]

Individual differences were measured using *HEXACO-PI-R* (Lee & Ashton, 2004), which measures six personality traits: Honesty-Humility, Emotionality, Extraversion, Agreeableness, Consciousness, and Openness to Experience. The measure consists of 60 questions (e.g., I prefer to do whatever comes to mind, rather than stick to a plan) and asks participants to rate their answer on a 5-point scale (ranging from *strongly disagree* to *strongly agree*).

Participants were also asked to fill out a *Locus of Control measure* (Rotter, 1966) consisting of 29 forced choice questions. There were six filler questions and 23 scored questions (e.g., A. Many of the unhappy things in people's lives are partly due to bad luck. B. People's misfortunes result from the mistakes they make.). Participants were asked to indicate which statement they agreed with more. Higher scores on this questionnaire indicate stronger external locus of control.

At the end of each task participants were given *End of Task Questionnaires*, which assessed participant's perception of frequency of wins and losses as well as confidence in their predictions of the outcome. Both questionnaires also included open ended questions on the use of strategies.

Doors Task.

See Appendix 2.2 for instructions, details regarding visual angles and average number of trials for each condition. Figure 3.2 shows a schematic representation of the task design. This task was based on the Hajcak et al. (2007) gambling task, measuring

[8] Note: The study also included a number of individual difference measures that are not part of the dissertation (but are a part of a bigger study), and thus, are not reported here.

the participant's predictions of the outcome. Participants were presented with four doors on the screen and told that some doors contained a reward of 5 cents behind them. A white '1', '2' or '3' cue was presented underneath the doors and indicated how many doors contained a reward (i.e., .25, .50 and .75 probability of winning). The page stayed up on the screen until participants made their choice using a response box, with buttons numbered one through four. Once the response was made, the chosen doors was highlighted with a blue border for 1000 ms. Participants were the asked "Do you think you will win on this trial?" and responded "yes" or "no" by pressing a key on the response pad. The question was presented underneath the doors, with the chosen door highlighted in blue, until a response was made. Following their prediction (1000 ms ISI), the chosen door was 'opened' to revealed either a reward ("$") or lack of thereof ("X"). The feedback stayed on the screen for 1000 ms. The intertrial interval (i.e., between the feedback and the onset of the cue) was 1000 ms. Unknown to the participants, the outcome on each trial was predetermined (i.e., everyone got the same outcome and order of the outcomes regardless of the door that was chosen) such that overall everyone won 25% of the time on the 1-cue trials, 50% of the time on the 2-cue trials and 75% of the time on the 3-cue trials.

The task consisted of four blocks of 84 trials (336 trials in total) and a six-trial practice session. The practice session was excluded from the analysis. Participants were informed of their running total in the task prior to the onset of the break, the length of which was determined by the participants. The task took approximately an hour to complete. As the outcomes were predetermined all participants received the same amount of winnings at the end of the task ($15).

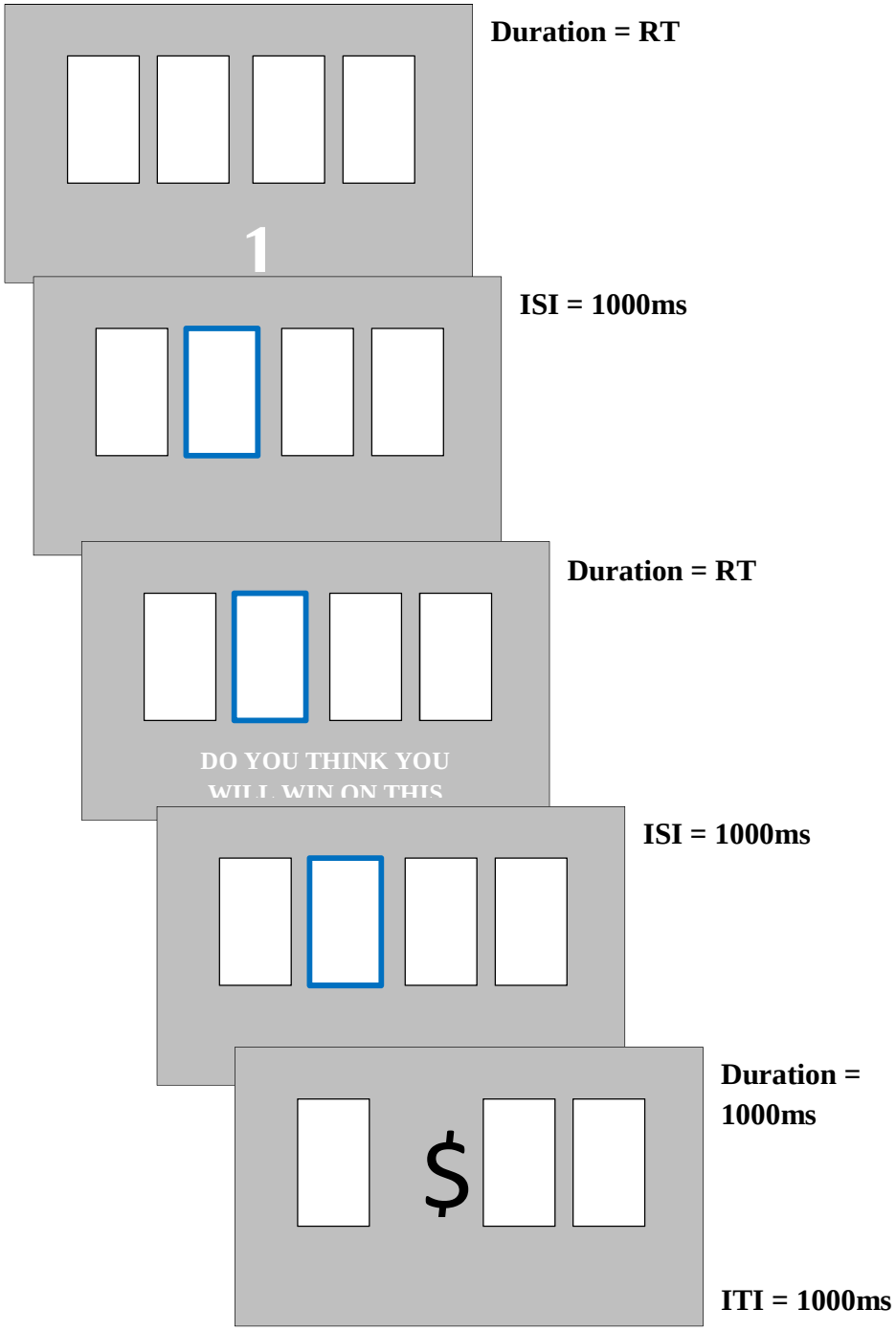

Figure 3.2. Schematic representation of events during the Doors task.

Time Estimation Task.

The Time Estimation task was adapted from Miltner, Braun, and Coles (1997). See Figure 3.3 for the schematics of the task design. As in the original task, participants were

informed that the goal of the task was to estimate an interval of 1 second by pressing a response key when they think that 1 second had elapsed relative to a cue (see Appendix 2.2 for instructions). In this version of the task, two types of cues were used: a green square indicating an easy trial and a red square indicating a hard trial. In order to increase the strength of the manipulation easy and hard trials were presented in blocks of 10 trials each, with a warning slide (1000ms) which contained words “Easy” or “Hard” prior to the presentation of the first cue (i.e., this slide appeared every 10 trials). Each trial started with the presentation of the cue for 500ms, followed by a grey screen (i.e., the estimation period). The estimation period was terminated once the response was made or after 2000ms. Following the termination of an estimation period, a grey screen was presented for 1000ms to ensure participants had a harder time estimating their performance, as well as preventing the contamination of the ERP waveforms by the response. Following this, feedback (“WIN!” or “LOSE!”) was presented for 1000ms. If the reaction time was 0 or longer than 2 seconds, “Too Slow!” feedback was presented. These trials were not analysed.

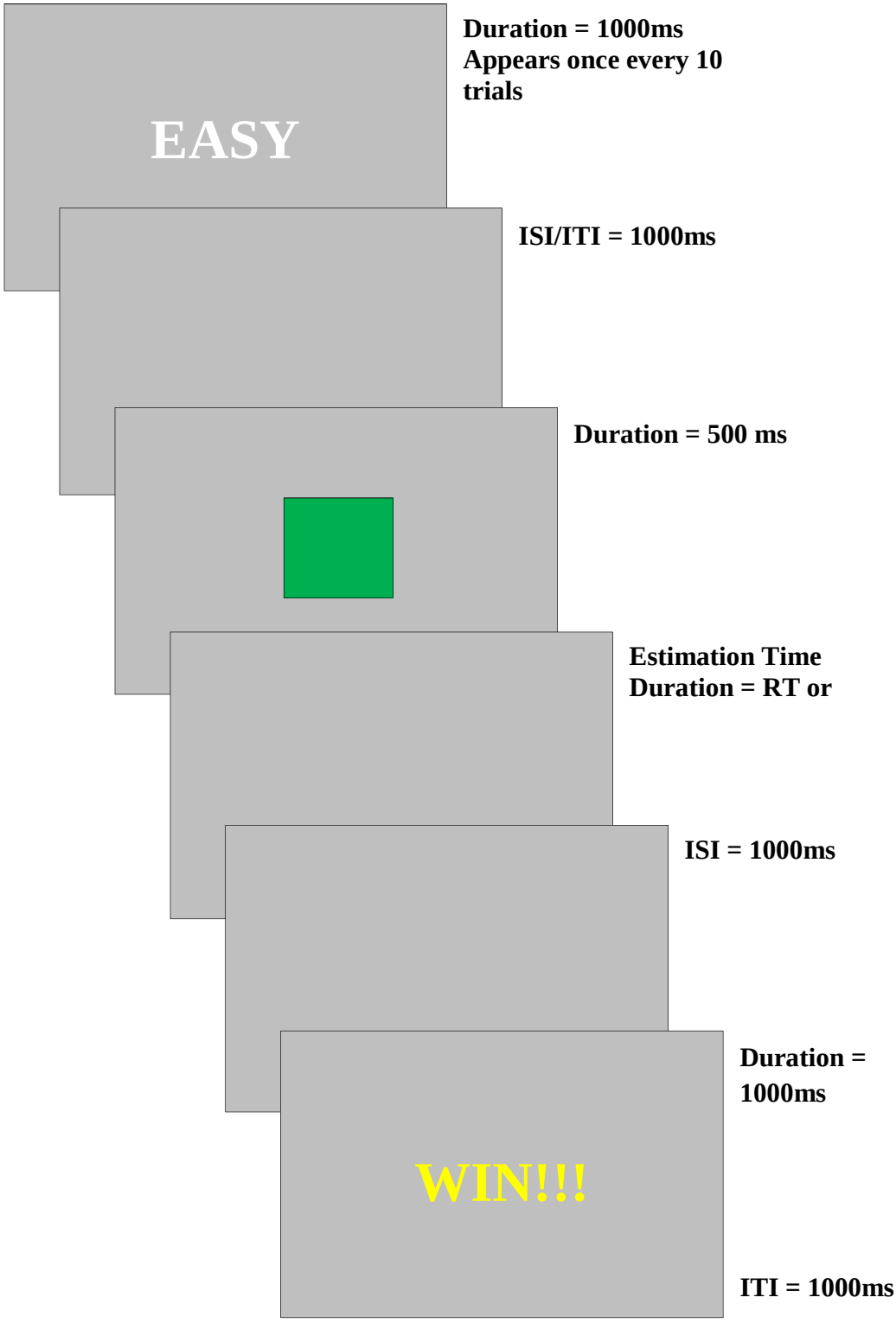

Figure 3.3. Schematic representation of events during the Time Estimation task.

Similar to the Doors task, the feedback on each trial was predetermined and was independent of participant's actual response, except for "Too Slow!" trials. In order to disguise this, an easy set of trials started with more frequent wins and hard trials started with frequent losses. This was done only in the beginning of the task, with the assumption that after multiple trials participants will not be consciously aware of the frequency of wins and losses for each cue block. Thus, by the end of the task, the frequency of wins and losses were equal ensuring that there will be no effects of frequency and probability on the FRN, and allowing us to examine if the FRN can be manipulated solely through instructions (i.e., manipulating cognitive state of the participant).

The task consisted of three blocks with 80 trials per block (240 trials in total) and 6 practice trials, which were excluded from all of the analysis. At the end of each block participants were shown their running total and were given a short break. The length of the break was determined by the participants. The task was 20 min in length on average.

Participants were told that each trial was worth 10 cents (i.e., they could win or lose 10 cents per trial depending on their performance). In order to ensure that each participant won something at the end of the task, given equal numbers of wins and losses, each win trial added 16 cents to the running total and each loss trial subtracted 8 cents from the running total. Participants won $10 on average (with variations due to "Too Slow!" trials, which had no impact on the running total).

Procedure

An online advertisement (on www.kijiji.ca) was used to recruit participants. Individuals were asked to call the lab for screening and scheduling of the testing session.

Upon first contact, interested individuals were informed about the study (i.e., EEG recording procedure, short overview of the tasks as well as compensation amounts) and were screened for neurological disorders (e.g., epilepsy), mental health difficulties (e.g., depression), use of medication, head injury and age (inclusion criterion: between 19 and 50 years). Participants were also screened using the PGSI to ensure a sufficient number of individuals in each group. Initially anyone scoring zero on the PGSI was admitted to the study, but later on interested individuals were also screened using the GBQ. This was necessary because the no-risk gambling group consisted mainly of recreational gamblers, who reported no maladaptive behaviour but engaged in almost the same amount of gambling activities as the at-risk gamblers.

Eligible participants were asked to come into the Brock University Cognitive and Affective Neuroscience lab for a three-hour testing session. All participants were shown the EEG system and given a consent form (see Appendix 2.1), which was discussed with the experimenter and signed. The participants were then fitted with the 128-channel Biosemi sensor net and seated in a comfortable chair (see Appendix 1.4 for channel layout). During the fitting of the sensor net, participants were asked to fill out a questionnaire package on a laptop (using www.fluidsurveys.com). Upon completion of the questionnaires, participants completed the Time Estimation and the Doors tasks. The tasks were counterbalanced, such that 20 people completed the Doors task first. Both tasks were presented using E-Prime software (Psychological Software Tools, Inc., 2004). Participants were given the Time Estimation and Doors *End of Task Questionnaires* immediately after completing each task.

Upon completion of the tasks, the sensor net was removed and participants were allowed time to clean up. Finally, participants were debriefed regarding the nature of the tasks (i.e., that outcomes were not dependent on performance) and anyone who reported engaging in gambling activities were given a "Responsible Gambling" brochure with information of local helplines. All participants were paid $25 on average for their 'performance' on the tasks and additional $30 for participating in the study (the rate of $10/hour). The study was approved by the Brock University Research Ethics Board (see Appendix 1.1).

EEG Recording.

The EEG recording process, data extraction and cleaning procedure was the same as in Study 1. After removal of muscle artifacts and eye blinks, the data were segmented around the onset of the feedback in each task, resulting in four conditions per task: expected win/loss and unexpected win/loss. In the Doors task, the outcomes were divided into expected and unexpected based on the participant's predictions (e.g., predicted a win but obtained a loss = unexpected loss). In the Time Estimation task outcomes were divided based on the type of block, such that during 'easy' blocks wins were considered expected and losses unexpected, and vice versa for the 'hard' blocks. Each of the stimulus-locked epochs had a 200ms baseline and were 1200ms in total length. After segmentation, the data were further cleaned using automatic artifacts rejection tool in the EEGLab using default criteria values. The segments were then averaged to create a single segment per condition for each of the participants. A number of participants were missing midline channels corresponding to FCz, Fz, Cz and Pz, therefore to maintain consistency, these channels were interpolated by a spherical spline for all of the

participants. The scalp data along the midlines were then exported to ERPScore (Segalowitz, 1999) and manually scored for the FRN peak amplitude. The FRN was defined as the most negative peak between 200 and 300 ms. Difference waves were created for expected and unexpected conditions in each task by subtracting waveforms following losses from waveforms following wins. This was done to be consistent with current FRN literature, which suggests that the FRN consists of a negativity and a reward positivity occurring simultaneously (Holroyd et al., 2008). Average amplitude was then calculated for each of the conditions at the times of the FRN (200 to 320ms). This measure of the FRN-valence effect will be further referred to as the difference-wave measures. Both measures, peak and difference-wave amplitudes were then exported to SPSS for further analysis. As in Study 1, the number of original Biosemi channels was reduced to three midline channels (Fz, FCz and Cz) by selecting a maximal FRN peak amplitude. This was done in order to reduce the number of statistical comparisons and to take into account that there are individual differences in brain morphology yielding maximum amplitudes at slightly different locations.

Data analysis

Validity checks and behavioural data.

A series of statistical analyses was conducted on the responses on the *End of Task Questionnaires*, frequency of predicted wins/losses as well as reaction times in each task. This was done in order to examine whether the tasks differed in levels of perceived sense of control and whether participants approached each type of trial on the tasks in a similar manner. Additionally, the reaction times observed on each type of trial were compared

between the two groups of participants (nPG and PG) to examine whether gambling status had an effect on behaviour during the tasks.

ERP measures.

A series of mixed repeated measures 2 (PG vs nPG) x 2 (Doors vs. Time Estimation) x 2 (Expected vs. Unexpected) x 2 (Loss vs. Win) x 3 (Fz, FCz, Cz) ANOVAs were conducted on the FRN peak amplitude and latency to investigate any potential interactions between gambling status and effects of task characteristics on the FRN. A follow up analysis using repeated measures ANOVAs was conducted to further examine any interactions. A similar analysis was carried out on the difference wave measures. Finally, these analyses were repeated examining any differences in the FRN measures in the extreme groups (i.e., non-gamblers and high risk PG).

Individual differences.

Prior to examination of any relationships between individual differences and ERP measures, a series of analyses were conducted to investigate whether the two groups differed on any of the measures. Additionally, correlational analyses were conducted to examine whether personality measures were related to the measures of gambling behaviour. Additionally, ERP measures were used in a multiple regression model as predictors of gambling behaviour to examine the relationship between the activity observed after each type of feedback presentation and gambling status.

Results

Validity Check and Behavioural Data

In order to examine whether the two groups differed in their perception of the tasks, a series of Mann – Whitney U tests were conducted on the *End of Task Questionnaire* data.

Non parametric tests were chosen as the data were not normally distributed due to the nature of the scale (ranging from '0' to '5'). There were no significant differences between the two groups in their approach (e.g., how hard did you try) or perception (e.g., was the feedback helpful?) of the tasks (see Table 2.2 and 2.3). There were no significant differences in any of the responses between groups. The proportions of participants reporting use of some strategy for the Time Estimation task did not differ for the two groups ($\chi^2 = 0.48$, $p = .489$). None of the participants reported using a strategy for the Doors task. Thus, participants reported approaching the tasks (e.g., use of strategy), perceiving the difficulty (e.g., how hard did you try) and proportions of winning/losing on each type of cue in a similar manner regardless of their PG status.

In the Doors task, participants were explicitly asked to predict whether they would win on each trial. These data were analysed using a mixed 2 (nPG vs. PG) x 3 (cue type) ANOVA to examine if reward expectations (i.e., number of trials reward was predicted) varied based on group membership and type of cue. The two groups did not significantly differ in their overall expectations of reward (F (1,39) < 0.01, $p = .957$, $p\eta^2 < .001$; Table 2.4) and there was no significant group by cue interaction (F (2,78) = 0.43, $p = .623$, $p\eta^2 = .011$), further supporting the hypothesis that the two groups of participants approached the task in a similar manner. Finally, there was a main effect of cue type (F (2,78) = 72.95, $p < .001$, $p\eta^2 = .652$), such that participants predicted a win most often on the '3' cue trials and least often on the cue '1' trials (post hoc $p < .001$ for all of the comparisons using Bonferroni correction). Thus, the participants were aware of the probabilities of winning on each trial and adjusted their expectations accordingly.

To test the manipulation of sense of control, responses to two questions (Did you feel you could predict the outcome?, How confident were you in your predictions?) were compared between the tasks using a Wilcoxon Signed Ranks Test. Participants were marginally more confident in their predictions during the Time Estimation task (p = .063), suggesting that they were under the impression that the outcomes depended on their performance. Although participants felt more control in the Time Estimation task, the self-reports of accuracy of predictions did not differ between the tasks (p = .106). If the FRN represents evaluation of the outcome based on expectations and participants did not perceive themselves to be less accurate on one task or the other (i.e., surprised more often on one), these data suggest that any effects of expectation on the FRN observed in the tasks should have a similar pattern. To examine the manipulation of expectation in the Time Estimation task, self-reports of effort on easy and hard trials were compared using the same non-parametric test. Participants reported trying significantly harder on the hard trials compared to easy trials (p < .001).

In order to further ensure that the participants did not significantly differ in their approaches to the tasks, reaction times for nPG and PG were compared in a series of independent t-tests (Table 2.5). There were no significant differences between the groups in the average or cue-specific reactions times for either task, showing that previous gambling behaviour did not affect participants' approach to the task. All of the participants took roughly the same time to choose a door regardless of the type of trial (F (2, 80) = 1.91, p = .165, $p\eta^2$ = .046), suggesting that probability of the outcome did not influence the decision time. Similarly, the reaction times in the Time Estimation task did

not differ based on the type of cue (t (40) = .85, p = .399) or feedback obtained (F (3,120) = 0.64, p = .519, $p\eta^2$ = .016).

In summary, participants approached the tasks in a similar manner regardless of their gambling status. Both groups of participants were aware of probabilities of wins on each type of trial of the Doors task and adjusted their expectations of rewards accordingly. The probability of the outcome in the Doors task and type of trial (i.e., easy vs. hard) in the Time Estimation task had no effect on reaction times in either group. Thus, overall the two groups of participants approached and performed similarly on both tasks.

ERP data

Average ERP waveforms of all the conditions for each task (broken down by group) can be found in Figures 3.4 to 3.7. For overlays using original Biosemi channels see Appendix 2.3.

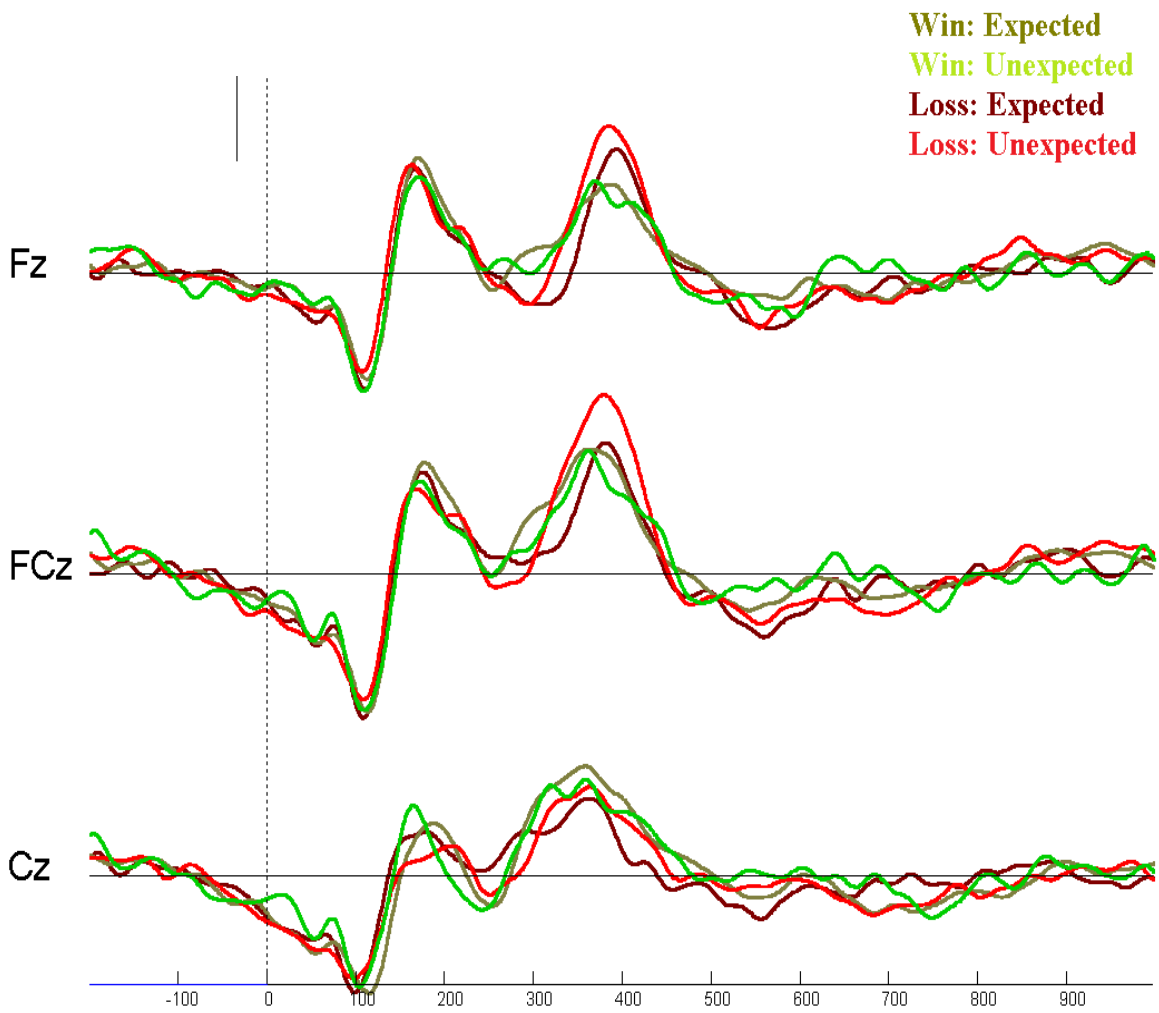

Figure 3.4. Average ERP waveforms elicited by the four types of feedback conditions in the Doors task (nPG group).

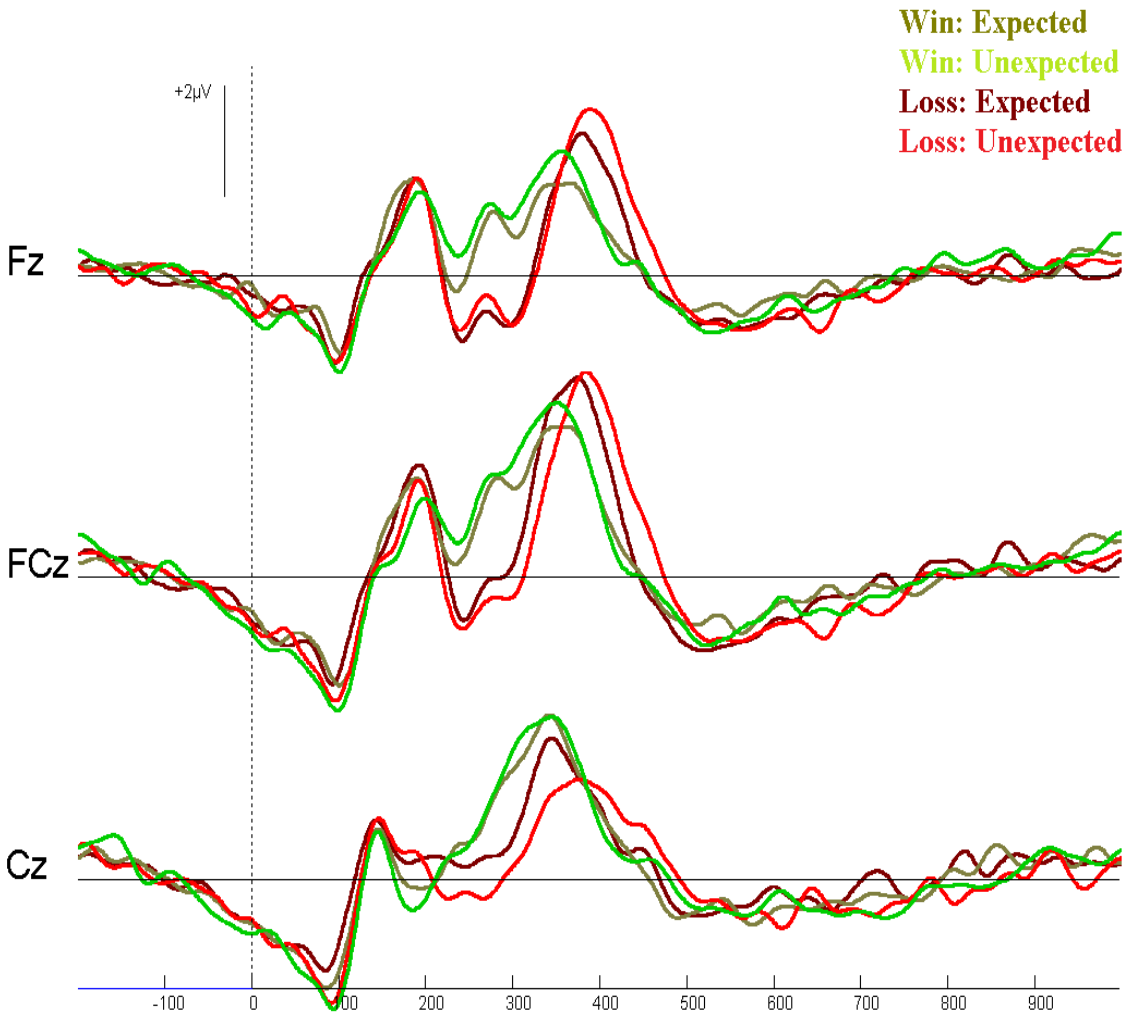

Figure 3.5. Average ERP waveforms elicited by the four types of feedback conditions in the Time Estimation task (nPG group).

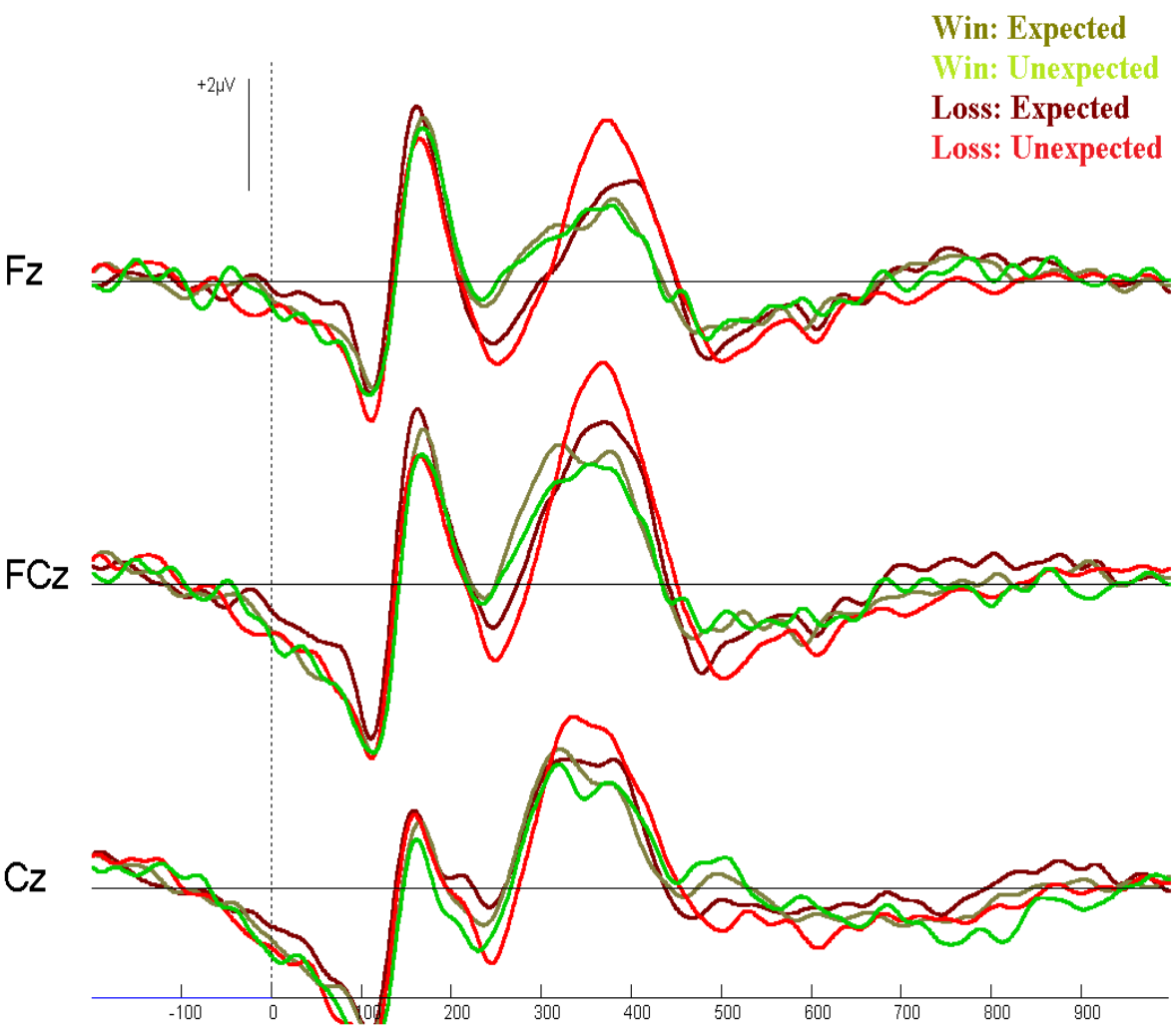

Figure 3.6. Average ERP waveforms elicited by the four types of feedback conditions in the Doors task (PG group).

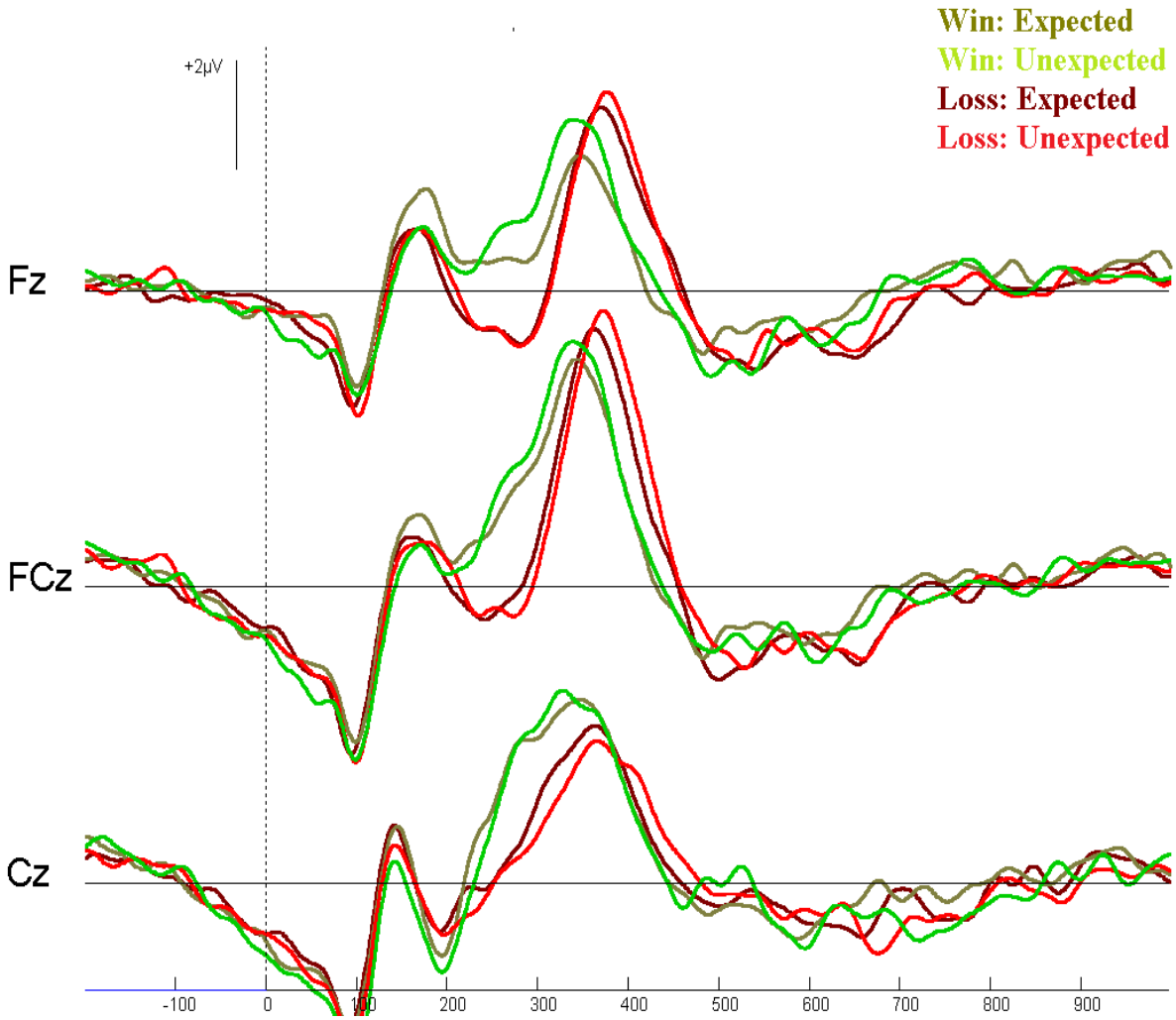

Figure 3.7. Average ERP waveforms elicited by the four types of feedback conditions in the Time Estimation task (PG group).

Peak Measures.

Effects of sense of control, expectation and group membership on the measures of FRN peak amplitude, latency and average amplitude of the difference waves at the time of the FRN were examined through the use of repeated measures ANOVAs. It was expected that the FRN following loss outcomes would be larger than that following win outcomes on both tasks. Similarly, the FRN elicited by unexpected outcomes was hypothesized to be larger than that observed after expected outcomes in both tasks. The FRN amplitude or the FRN-valence effect observed in the Time Estimation task was expected to be larger than in the Doors task due to greater perceived sense of control over the outcome in the Time Estimation task. This effect was expected to be significant in the nPG group but not in individuals at risk for problem gambling.

A 2 (Gambling group) x 2 (Task) x 2 (Expectations) x 2(Valence) x 3(Channel) mixed ANOVA was conducted on the peak FRN amplitude measures to examine potential interactions between the groups (Table 2.6). There were significant main effects of expectations (F (1,39) = 13.28, $p < .001$, $p\eta^2 = .254$), valence (F (1,39) =14.92, $p < .001$, $p\eta^2 = .277$) and channel (F (2,78) = 4.64, $p = .017$, $p\eta^2 = .106$). The main effect of valence was superseded by two-way interactions with channel (F (2, 78) = 29.95, $p < .001$, $p\eta^2 = .434$) and task (F (1,39) = 11.56, $p = .002$, $p\eta^2 = .229$). As no specific hypotheses were made regarding the distribution of the effects across channels, any interactions with channel were not followed up. Additionally, a task by expectation (F (1, 39) = 7.26, $p = .010$, $p\eta^2 = .157$) interaction was observed (superceding the main effect of expectations). There were no significant between-subjects effects (F (1,39) = 1.48, $p = .231$, $p\eta^2 = .037$), but there was a significant three-way interaction between

group, task and expectations (F (1,39) = 4.56. p = .039, $p\eta^2$ = .105) and a marginally significant three-way interaction between group, valence and channel (F(2,78) = 3.43, p = .057, $p\eta^2$ = .081).

In order to better understand these two interactions (task x valence, and group x task x expectations), a follow-up 2 (expectations) x 2 (valence) x 3 (channel) repeated measures ANOVA was conducted for each task. As this analysis does not directly address the valence by task interaction, a repeated measures 2 (task) x 2 (expectation) x 3 (channel) ANOVAs were also conducted for each type of outcome (i.e., win/loss). It was hypothesized that gamblers and non-gamblers might react differently to the manipulations of sense of control and expectations, these analysis were conducted for each group of participants separately (i.e., nPG and PG).

Task by Valence interaction.

Participants not at risk for PG. Two repeated measures ANOVAs (one for losses and one for wins) were conducted to examine the task by valence interaction observed in the mixed ANOVA analysis (Table 2.7). For the FRNs elicited by losses, there was a main effect of task (F(1,21)=16.82, p=.001, $p\eta^2$ = .445), such that losses elicited a larger FRN in the Time Estimation task (M = -2.13, SE = 0.29) compared to the Doors task (M = -1.25, SE = 0.16). Additionally, there was a main effect of expectation (F (1,21) = 4.55, p = .045, $p\eta^2$ = .178), such that unexpected losses (M = -1.87, SE = 0.20) were followed by a larger FRN than expected losses (M = -1.50, SE = 0.25). There were no significant main effects or interactions in the ANOVAs conducted using FRNs elicited by wins. Thus, in this group, any effects of sense of control and expectation on the FRN were driven by the FRNs elicited by loss outcomes.

Participants at-risk for PG. Similar to the analysis done in the nPG group, two repeated measures ANOVAs were run in order to address the task by valence interaction observed in the mixed ANOVA (Table 2.8). There was a significant interaction between task and valence in FRN amplitude following wins (F (1,18) = 4.50, p = .021, $p\eta^2$ = .200) and losses (F (1,18) = 8.15, p = .011, $p\eta^2$ = .312), such that unexpected outcomes produced larger FRNs compared to expected outcomes only in the Doors task (Figure 3.8). FRNs following wins were also significantly different based on the expectedness of the outcome (F (1,18) = 7.75, p = .012, $p\eta^2$ = .301), but FRNs elicited by losses were not (F (1,18) = 1.88, p = .188, $p\eta^2$ = .094). Additionally, FRNs elicited by wins were significantly larger in the Doors task (M = -1.83; SE = 0.30) compared to the Time Estimation task (M = -1.35; SE = 0.37; F (1,18) = 4.81, p = .042, $p\eta^2$ = .211). Thus, any sense of control and expectation effects observed in this group were driven primarily by the FRNs following wins.

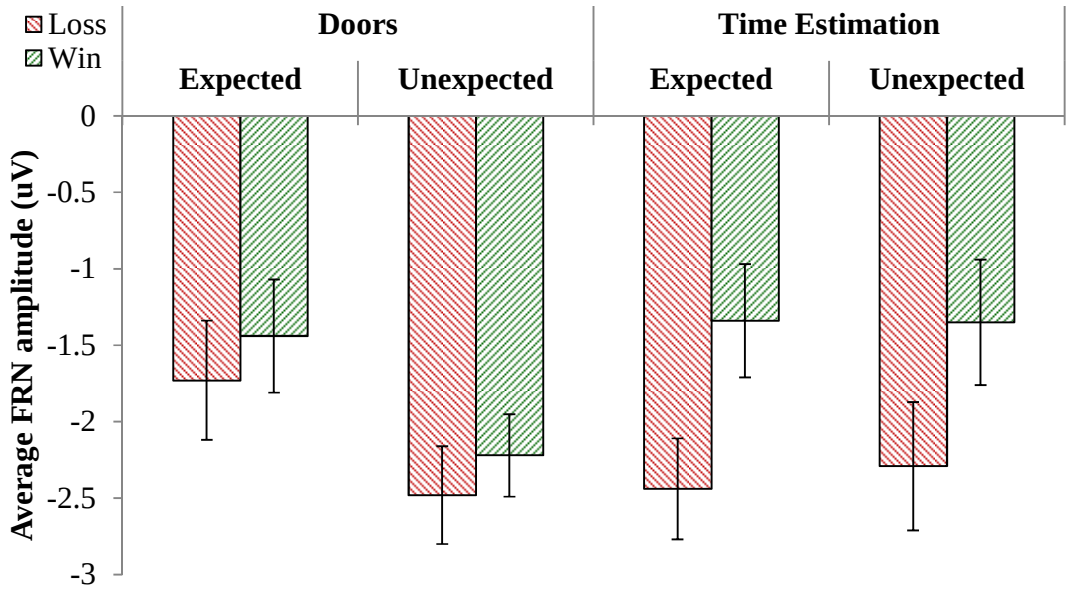

Figure 3.8. Graphical representation of the interaction between task and valence in the PG group.

Group by Task by Expectation follow up.

Participants not at risk for PG. Repeated measures ANOVAs (2 (Expectations) x 2 (Valence) x 3 (Channel)) were conducted for the Doors task (Table 2.9). Only the effect of expectation was significant (F (1,21) = 6.56, p = .018, $p\eta^2$ = .238) such that unexpected outcomes elicited a larger FRN peak amplitude (M = -1.44, SE = 0.19) compared to expected feedback (M = -1.13, SE = 0.19). In the Time Estimation task, the effect of expectations were not significant (F (1,21) = 2.31, p = .144, $p\eta^2$ = .099; Table 2.9). However, there was a significant effect of valence in the Time Estimation task (F (1,21) = 14.76, p = .001, $p\eta^2$ = .413) with loss outcomes (M = -2.13, SE = 0.29) having larger peak FRN amplitude compared to wins (M = -1.10, SE = 0.29) but not in the Doors task (F (1, 21) = 0.94, p =.762, $p\eta^2$ =.040). No other significant main effects or interactions of interest were observed. Thus, it appears that manipulation of expectations worked only in the Doors task and the FRN-valence effect was larger in the Time Estimation task.

Participants at risk for PG. Two 2 (Expectations) x 2 (Valence) x 3 (Channel) repeated measures ANOVAs were conducted to examine whether the patterns of FRN sensitivity differed between tasks (Table 2.10). Similar to the nPG group, in the Doors task unexpected feedback (M = -2.20, SE = 0.35) elicited larger FRN amplitude compared to expected feedback (M = -1.59, SE = 0.36; F (1,18) = 14.91, p = .001, $p\eta^2$ = .453; Table 2.10). Additionally, a significant valence by channel interaction was observed (F (2,36) = 8.46, p = .004, $p\eta^2$ = .320) such that the FRN elicited by losses was larger than that elicited by wins, but only at Fz and FCz (Figure 3.9). This observation was statistically tested by conducting a 2 (expectation) x 2 (valence) x 2 (channel)

repeated measures ANOVA including only the FRNs measured at Fz and FCz. There was a main effect of valence (F (1,18) = 5.49, p = .031, $p\eta^2$ = .234), such that losses (M = -2.12, SE = 0.33) elicited larger FRN compared to wins (M = -1.44, SE = 0.29). Thus, unlike the nPG group, outcomes in the Doors task elicited FRN-valence effects in individuals at risk for problem gambling behaviour.

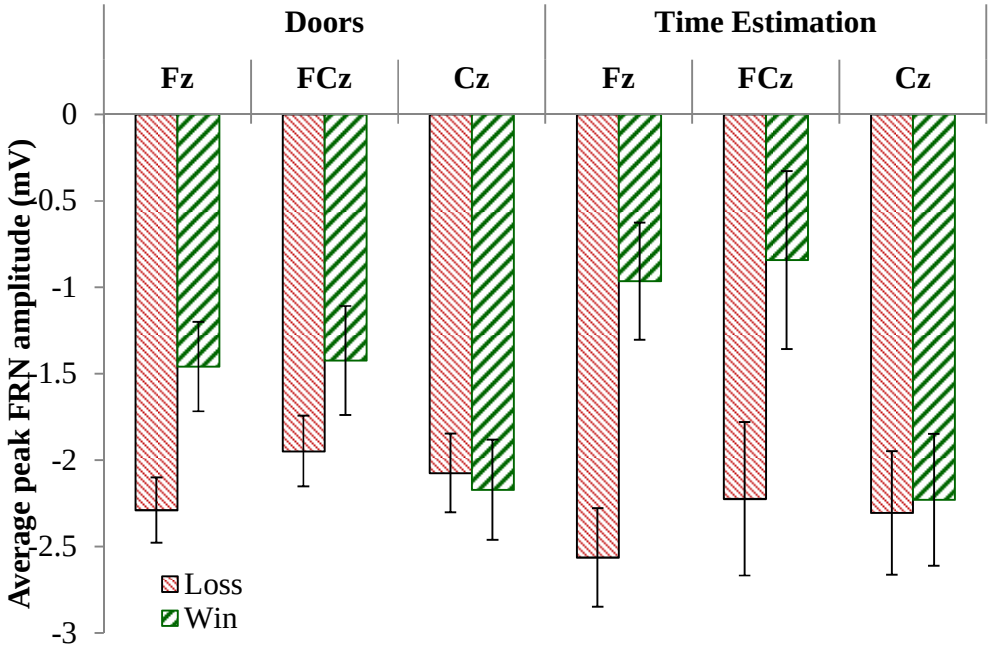

Figure 3.9. Graphical representation of interactions between valence and channel observed in the PG group.

In the Time Estimation task, main effect of valence (F (1,18) = 8.70, p = .009, $p\eta^2$ = .326) was significant in the expected direction (loss: M = -2.36, SE = 0.34; wins: M = -1.35, SE = 0.37). There also was valence by channel interaction (F (2, 36) = 15.86, p < .001, $p\eta^2$ = .468), similar to the one observed in the Doors task showing larger FRN-valence effects at frontal channels (Figure 3.4). As was observed in the nPG group,

participants in the PG group did not show any significant effects of expectation on the FRN peak amplitude (F (1,18) = 0.24, p =.631, $p\eta^2$ = .013).

Extreme groups analysis.

There was no support for the predicted difference in FRN response between PG and nPG groups as no significant effect of group membership was observed in the mixed measures analysis. It should be noted that both groups were heterogeneous, such that PG group included gamblers with low, medium and high risk of PG, whereas nPG group included individuals who do not gamble at all (n = 10) and recreational gamblers (i.e., engage in gambling activities but score "0" on the PGSI). Individuals had to score at least "1" on the PGSI were placed in the PG group. Thus, the reward system activation elicited by the feedback could have been very similar between recreational gamblers and those at low risk for PG. In order to confirm that problem gambling status had no effect on the FRN response, as suggested by the results of peak FRN amplitude analysis, the analysis were repeated on the two extreme groups (i.e., non-gamblers (NG, n = 10) and higher risk gamblers (hPG, n = 8)).

A mixed repeated measures 2 (group) x 2 (task) x 2 (expectations) x 2 (valence) x 2 (channel) ANOVA was conducted on the peak FRN amplitude (Table 2.11). Channels Fz and FCz were chosen based on the results of previous analysis, as the expectation and valence effects observed appeared to be more frontally distributed. There were no significant interactions between task/valence/expectation and group membership. Two-way significant interactions were observed between task and valence (F (1,16) = 26.60, p < .001, $p\eta^2$ = .624), and expectation and channel (F (1,16) = 19.32, p < .001, $p\eta^2$ = .547). Similar to the analysis of nPG and PG groups there was a main effect of expectations (F

(1,16) = 4.97, p = .040, $p\eta^2$ = .237). These interactions were similar to the patterns observed when nPG and PG groups were compared, thus no further follow up analysis was conducted.

Summary.

Summary of the analysis conducted on the peak data can be seen in Figure 3.10.

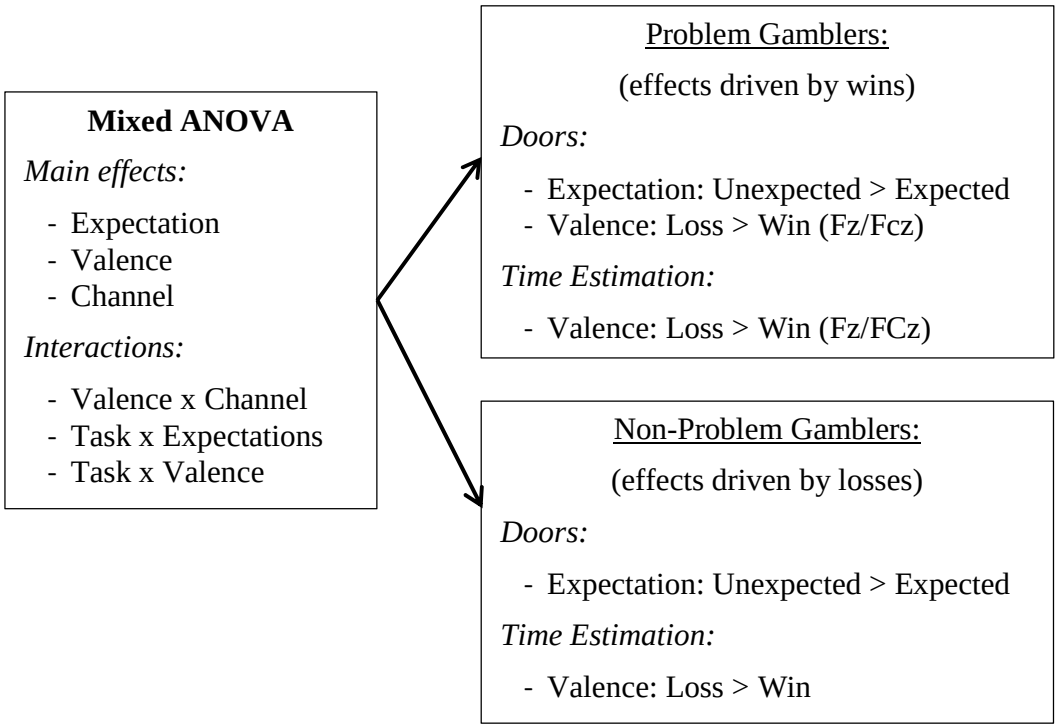

Figure 3.10. Graphical representation of significant effects observed in the analysis of the peak FRN data.

The hypothesis regarding effects of expectation on the FRN peak amplitude was partially supported such that unexpected outcomes elicited larger FRNs compared to expected outcomes, but only in the Doors task (i.e., bottom-up). Similarly, the hypothesis regarding the effects of sense of control on the FRN-valence sensitivity was partially supported in the nPG group, such that valence effects were observed in the Time Estimation task and not in the Doors task. Both groups of participants showed an FRN-

valence effect in the Time Estimation task, but only the PG group showed valence effects in the Doors task. Thus, individuals at risk for problem gambling seemed to be more sensitive to valence information in the gambling task compared to their nPG counterparts. This effect was larger in the Time Estimation task ($p\eta^2$ = .326) compared to the Doors task ($p\eta^2$ = .234), suggesting that in this group higher levels of perceived control over the outcome led to an increase in the FRN valence effects. Finally, effects of expectation and sense of control were driven by FRNs elicited by losses in the nPG group, and mostly by the FRN elicited by wins in the PG group, suggesting that at-risk gamblers are less sensitive to loss outcomes and more sensitive to rewards compared to not at-risk individuals.

Latency analysis.

Previous research by Oberg et al. (2011) suggests that gambling experience can modulate the latency of the FRN rather than its peak amplitude. More specifically, gamblers were found to differentiate the valence of the outcome earlier than non-gamblers. In order to examine this hypothesis a mixed ANOVA was conducted on the latencies of peak FRN amplitude. The three midline channels (Fz, FCz, Cz) were included in the setting up of the analysis, such that latencies analysed were consistent with the channel showing maximal FRN amplitude for each participant.

In our data, contrary to the hypothesized effects, there were no significant effects or interaction with gambling status (Table 2.12). There was a main effect of expectation (F (1,39) = 4.81, p = .033, $p\eta^2$ = .111) such that expected outcomes elicited an earlier FRN (M = 239.42, SE = 3.92) compared to unexpected feedback (M = 244.31, SE = 3.87). Losses were followed by a later FRN (M = 247.55, SE = 4.28) compared to wins (M =

236.18, *SE* = 4.15; *F* (1,39) = 8.39, *p* = .006, $p\eta^2$ = .177). Finally, there was a main effect of channel (*F* (2, 78) = 36,86, *p* < .001, $p\eta^2$ = .486) such that FRN peak latency decreased as the channels became more central (Fz: *M* = 252.48, *SE* = 4.24; FCz: *M* = 243.32, *SE* = 4.05; Cz: *M* = 229.80, *SE* = 3.81). Thus, in contrast to the Oberg et al. (2011) findings, in this study individuals at risk for PG did not differentiate between the valence of outcomes earlier than nPG group[9].

Difference wave analysis.

In order to examine the effects of group membership, task and stimulus expectedness on the reward positivity observed at the time of the FRN, average amplitude of difference waves was analysed. To be consistent with the literature, loss trials for each condition were subtracted from the win trials (Holroyd, Pakzad-Vaezi, & Lee, 2008). It was expected that higher levels of sense of control in the Time Estimation task would increase the FRN-valence effect (i.e., more positive FRN for wins and more negative FRN for losses). Thus, the difference-wave amplitude was expected to be greater in the Time Estimation task compared to the Doors task. Based on previous research, it was hypothesized that unexpected wins will produce a larger reward positivity (i.e., more positive FRN) compared to expected outcomes (Holroyd, Krigolson, & Lee, 2011). Similarly, unexpected losses were hypothesized to produce larger FRNs (i.e., more negative FRNs; Bellebaum & Daum, 2008; Kobza et al., 2011). Thus, the average amplitude of the difference waves was hypothesized to be larger following unexpected outcomes compared to expected ones.

[9] Note: When this analysis was repeated using non-gamblers and high risk gamblers no significant group effects were observed.

A mixed repeated measures ANOVA examining the effects of group membership, task and expectation was conducted on the four frontal midline sites representing Fz and FCz from the original Biosemi montage (C14, C13, C12, C11). These channels were chosen based on the results of the peak FRN amplitude, which showed that valence and expectation effects in each task were stronger at frontal channels. The data were screened for outliers and violations of normality prior to conducting statistical analysis.

Significant main effects of task (F (1,39) = 33.18, $p < .001$, $p\eta^2 = .460$) and expectation (F (1, 39) = 5.94, $p = .020$, $p\eta^2 = .132$) were observed in the overall repeated measures ANOVA (Table 2.13). As predicted, average amplitude of the difference waves was larger in the Time Estimation task (M = 1.40, SE = 0.14) compared to the Doors task (M = 0.76, SE = 0.13) and unexpected outcomes elicited a more positive difference wave amplitude (M = 1.09, SE = 0.14) compared to expected outcomes (M = 0.76, SE = 0.13). As there were no significant interactions with the task used to elicit FRNs, the effect of expectation was not driven by only one of the tasks.

It should be noted that there was no significant FRN-valence effect in the Doors task in the nPG group, which could have attenuated the overall reward positivity observed in this task, as the magnitude of the differences between win and loss conditions (i.e., reward positivity) is dependent on the size of the FRN-valence effect. Thus, one could argue that smaller reward positivity observed in the Doors task was due to participants not processing the valence of the outcome. In order to address this argument, the analysis were repeated with PG group only, as these participants showed significant FRN-valence effects in both tasks.

Results of this analysis (Table 2.14) showed that difference wave amplitude observed in the Time Estimation task (M = 1.49, SE = 0.20) was larger than that observed in the Doors task (M = 0.68, SE = 0.21; F (1,18) = 11.49, p = .003, $p\eta^2$ = .390). The effects of expectation on the amplitude of the difference waves were only marginally significant (F (1,18) = 3.87, p = .065, $p\eta^2$ = .177) but were in the hypothesized direction such that unexpected outcomes (M = 1.20, SE = 0.20) elicited a larger reward positivity compared to expected outcomes (M = 0.97, SE = 0.18). In order to examine if the effect of expectation observed in the mixed ANOVA was driven only by one of the groups (i.e., nPG) a similar analysis was conducted only including nPG participants. As in the PG group, the effect of expectation was also marginally significant (F (1,21) = 3.39, p = .080, $p\eta^2$ = .139) in the expected direction (expected: M = 0.55, SE = 0.18; unexpected: M = 0.97, SE = 0.20). Thus, unexpected outcomes led to a larger reward positivity compared to expected outcomes in both groups (Figure 3.11). Lack of significant effects within each group suggests that this effect is rather small and requires greater power to be detected (i.e., larger sample size).

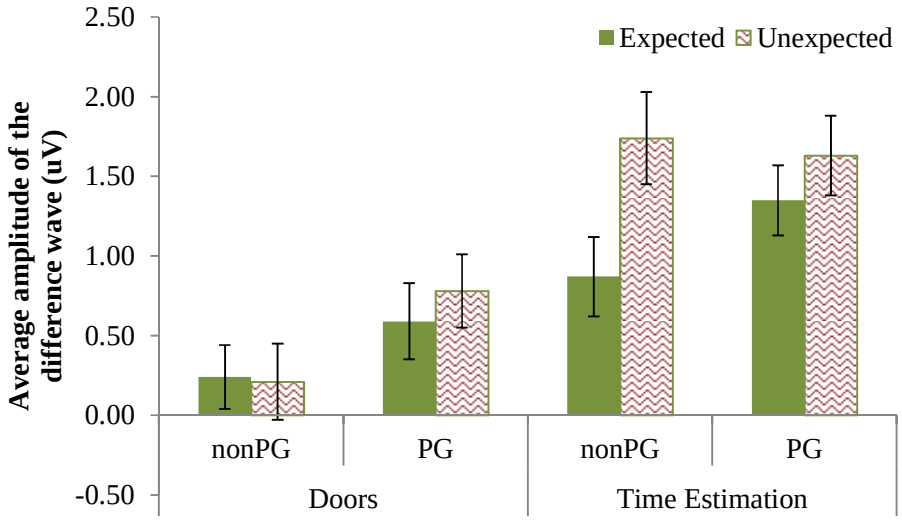

Figure 3.11. Graphical representation of expectation effects on the reward positivity in each group broken down by task.

In summary, the analysis of difference-wave amplitudes at the time of the FRN was consistent with the proposed hypotheses, such that greater positivity was observed in the Time Estimation task compared to the Doors task. This is likely due to the consistent FRN-valence effects which were observed in both groups, and a larger FRN-valence effect observed in the PG group, during the Time Estimation task compared to the Doors task. Unexpected outcomes elicited a larger positivity compared to expected outcomes; however, this effect was only marginally significant within each group, suggesting that the effect was very small and not driven by one specific task.

Individual Differences

In order to examine the relationship between gambling behaviour and personality, participants were divided as before into two groups to increase the number of subjects in each cell, thus increasing statistical power of the tests: no risk for PG (nPG) and at risk for PG (PG). There were no normality violations (i.e., tests of normality showed $p > .05$)

or outliers in the data (i.e., ±3SD). It was previously hypothesized that the groups might differ on some of the personality variables and these differences might be related to their responses to feedback stimuli. As there is no literature directly examining these relationships in problem gamblers, no directional hypotheses were made.

Gambling status.

A series of independent group t-tests were conducted to examine any potential differences on Locus of Control and personality (i.e., HEXACO) measures. There were significant differences between the groups on the subscales of Conscientiousness (t (38) = 2.91, p = .006) and Emotionality (t (37) = -2.33, p = .025; Table 2.15). Previous research (Twigger, 2010) has shown that high risk gamblers score lower on the subscales of Conscientiousness, Emotionality and Honesty-Humility compared to low-risk gamblers. Our data partially replicates these findings, such that individuals at risk for problem gambling reported lower levels of conscientiousness and higher levels of emotionality (Table 2.15).

It was hypothesized that any differences in personality variables observed between the groups would be mediated by ERP measures. As significant group differences were observed only using peak FRN amplitude and not latency or amplitude of the difference wave, FRN peak measures were chosen to test this hypothesis. If FRN response mediates the relationship between gambling status and personality, then variance in PGSI score accounted for by personality measures would decrease once FRN measures are entered in the model[10]. Prior to conducting the mediation analysis, relationships between FRN and PGSI score were examined to identify significant predictors that will be included in the model (Table 2.16). There were no significant relationships between FRN measured at Fz

[10] Note: Only channel Fz was used in this analysis to reduce the number of predictors.

and PGSI score, Conscientiousness or Emotionality scores. In order to conduct a mediation analysis first it must be shown that all of the variables in the model are significantly related. As no such relationships were found with FRN measures no mediation analysis was conducted.

In order to examine whether the change in ACC activity in response to expectancy, sense of control or valence is related to measures of individual differences, residual scores were calculated for each effect of interest. More specifically, changes in ACC activity due to valence were reflected in the residual loss-FRN amplitude after adjusting for the variance due to win-FRN amplitude. Similarly, expectation effects were obtained by adjusting for variance in unexpected outcomes due to expected outcomes and sense of control effects were obtained by regressing FRN amplitudes elicited in the Doors task on those elicited in the Time Estimation task. The unstandardized residuals obtained were first correlated with total PGSI score (i.e., gambling severity), Conscientiousness and Emotionality (Table 2.17). Similar to the FRN peak analysis, there were no significant relationships between any of the residuals and measures of individual differences or gambling severity, thus no further analysis was conducted.

Gambling behaviour.

To examine the potential relationships between gambling behaviour and measures of individual differences, a series of correlations were conducted.[11] More specifically, frequency of gambling behaviour and number of gambling activities engaged in the past year (measured with GBQ) were correlated with Locus of Control scores and HEXACO subscale scores (see Table 2.18). There was a significant correlation between the measure of gambling frequency and Conscientiousness (r (29) = -0.47, p = .011) and

[11] Note: Participants who reported not gambling at all (N = 10) were excluded from this analysis.

Honesty/Humility subscales (r (29) = -0.37, p = .049), such that individuals reporting higher levels of these personality traits gambled less frequently. Similarly, higher scores on the Agreeableness subscale was similarly related to lower frequency of gambling behaviour and fewer gambling activities involved in (frequency: r (28) = -0.46, p = .018; number of activities: r (32) = -0.42, p = .024).

Further investigation of these relationships was done using multiple linear regression analysis, predicting gambling frequency from HEXACO subscales of Agreeableness, Consciousness and Honesty/Humility (Table 2.19). The overall model was not significant (F (3,22) = 2.51, p = .084), but Agreeableness uniquely predicted 15.13% of variability in the frequency of gambling behaviour (p = .046). None of the other personality subscales were uniquely significant in the model. In other words, the ability to let go of wrongs and willingness to compromise (i.e., agreeableness) is uniquely related to decreased frequency and prevalence of gambling behaviour.

ERP measures and Gambling Behaviour.

Potential relationships between various FRN measures and gambling behaviour were examined with a number of correlations and regression models. In order the reduce the number of comparisons made, only channel Fz (i.e., C14, C13) was included in this analysis as the FRNs observed were most pronounced at this site. To further examine the potential effects of the ACC response to expectation and valence that contribute to the relationship with gambling behaviour a multiple regression was conducted predicting gambling behaviour from FRN measures within each task. This approach was used with the FRN peak, latency and difference wave measures.

Peak FRN.

FRN peak amplitude measured in the Doors task did not significantly predict gambling frequency in the past year (R^2 = 0.17, F (4, 25) = 1.24, p = .321) and none of the predictors were uniquely significant (Table 2.20). A similar lack of effects for the ERP measures were observed in the Time Estimation task (R^2 = 0.03, F (4, 25) = 0.17, p = .953). There were no relationships between number of gambling activities engaged in the past year and FRN peak measures in each task (Table 2.20; Doors: R^2 = 0.24, F (4, 26) = 2.10, p = .110; TE: R^2 = 0.11, F (4, 29) = 0.90, p = .478). However, FRNs elicited in the Doors task during unexpected losses uniquely predicted 19.00% of variance in number of gambling activities (p = .018), such that larger FRN peak amplitude correlated with lower number of gambling activities engaged in (r (31) = -0.48, p = .003). There were no significant unique predictors of variety of games engaged in and FRN peak amplitude in the Time Estimation task (R^2 = 0.12, F (4, 29) = 0.90, p = .478).

Relationships between changes in ACC activity and measures of gambling behaviour (i.e., frequency and number of gambling activities) were examined through the use of residual scores (Table 2.17)[12]. Changes in ACC activity in response to valence of the outcome in the Doors task were significantly correlated with number of gambling activities engaged in the past year (r = -0.47, p = .007). Furthermore, self-reported number of gambling activities engaged in was significantly correlated with changes in loss-FRN (i.e., FRN following loss outcomes) in response to expectedness of the outcome in the Doors task (r = -0.45, p < .012). This is not surprising given that the FRN elicited by unexpected losses in the Doors task was significantly related to number of gambling activities. Thus, the results of this analysis suggest that engagement in wider

[12] Description of analysis done to obtain residuals was described on page 139.

range of gambling activities is associated with a smaller FRN-response to unexpected losses.

FRN latency.

Similar analyses were conducted using peak FRN latency as predictor (Table 2.21). The overall model predicting frequency of gambling behaviour from FRN peak latency was once again not significant in either task (Doors: $R^2 = 0.17$, F (4, 25) = 1.30, $p = .298$; Time Estimation: $R^2 = 0.25$, F (4, 25) = 2.09, $p = .113$); there were no significant unique predictors. Similarly, no significant effects were observed when number of gambling activities was used as a predictor (Doors: $R^2 = 0.20$, F (4, 26) = 1.61, $p = .202$; Time Estimation: $R^2 = 0.25$, F (4, 26) = 0.88, $p = .492$). Similar to the peak analysis, changes in timing of ACC activity were examined by conducting a series of correlations between residual FRN latency and measures of gambling behaviour (Table 2.22). There were no significant relationships between any of the measures in changes in timing of ACC activity and gambling behaviour. Thus, none of the previously observed FRN latency effects were related to the gambling behaviour.

Difference wave amplitude.

In order to examine if the measure of reward positivity was related to gambling behaviour, a series of regressions was conducted using average difference-wave amplitude in each task as predictors using channels C14 and C13. The overall models predicting gambling frequency or number of gambling activities engaged in were not significant in either task (Table 2.23). Thus, the size of reward positivity observed in each task was not related to any of the measures of gambling behaviour.

Summary.

Two groups of participants were significantly different on measures of Conscientiousness and Emotionality, but neither of these measures were significantly related to peak FRN amplitude. Conscientiousness, Honesty/Humility and Agreeableness scales of the HEXACO were related to gambling frequency, but only Agreeableness accounted for unique variance in gambling frequency. The ERP measures were not significantly predictive of gambling frequency or total PGSI score. Larger FRNs following unexpected losses in the Doors task were predictive of lower number of gambling activities engaged in the past year. However, neither of the measures of ACC responsivity were related to personality variables of interest (i.e., Conscientiousness and Emotionality). Thus, the hypothesis of ACC activity mediating the relationships between personality and gambling severity was not supported.

Discussion

This study was conducted to examine the effects of expectations, sense of control and gambling behaviour on the FRN.[13] Sense of control was manipulated through the use of two tasks: Doors (low control) and Time Estimation (high control). In the Doors task participants were explicitly asked to predict the outcome; the feedback was divided into expected and unexpected outcomes based on these predictions. In the Time Estimation task, expectations were manipulated through instructions by telling participants that there were easy and hard trials. Wins were labeled as expected if the trial was easy, unexpected if the trial was hard and vice versa for loss outcomes. Frequency of wins and losses in each condition (i.e., easy vs. hard) did not differ by the end of the Time Estimation task.

[13] The interpretation of these results in light of the proposed model for FRN generation is presented in the General Discussion.

In the Doors task, the frequency of outcomes also did not differ by the end of the task as in the Time Estimation task, but varied within each type of trial (i.e., based on probability of winning signified by each cue). The outcomes were independent of participants' choices and performance in both tasks. Three measures of FRN variability were examined in this study: peak amplitude, latency of the peak amplitude and average amplitude of difference waves at the time of the FRN.

Within-subject effects

It was hypothesized that FRN would be modulated by expectation such that unexpected outcomes in both tasks would lead to larger FRN compared to expected outcomes. This hypothesis was supported only in the Doors task, where participants were explicitly asked to predict outcomes after being informed about probability of the reward. Consistent with previous research (Hajcak et al., 2007) this manipulation affected the FRN, supporting the hypothesis that ACC activity is modulated by probability-based expectations. In the Time Estimation task, expectations were manipulated through instructions and cues labeling the trials as 'easy' or 'hard'. Lack of significant effects of this manipulation on the FRN amplitude suggests either that (a) the manipulation did not work, or (b) the FRN is not modulated by non-probability based outcomes. Participants did report trying significantly harder on hard trials compared to easy trials, suggesting that expectations of success were lower in the "hard" trials". It is also possible that the FRN is modulated only by expectations based on probabilities of the outcome. However, given previous research showing that FRN is modulated by cognitive states and constructs (e.g., Yang, Gu, Tang, & Luo, 2013) it is unlikely that activity of the ACC, which was proposed to partially reflect prediction error signal generated in the reward

network, would not account for the subjective state of the individual. It is more likely that manipulations of cognitive state of the participant for each trial (i.e., expectations in the Time Estimation task) had an effect at a later stage of processing, after the initial prediction error signal and thus was not reflected in the FRN response.

Previous research has shown that both tasks elicit an FRN valence effect, such that losses are followed by a larger FRN compared to wins (e.g., Hajcak et al., 2007; Miltner et al., 1997). Thus, it was expected that all participants would show an FRN-valence effect. Furthermore, it was hypothesized that this effect would be increased in the Time Estimation task, due to a higher level of perceived control over the outcome (i.e., more investment in the outcome). Participants in the nPG group showed a significant FRN valence effect only in the Time Estimation task, partially supporting the hypothesis. Examination of FRN valence effects in the PG group, showed a larger effect size in the Time Estimation task ($p\eta^2$ = .326) compared to the Doors task ($p\eta^2$ = .234). Thus, as hypothesized, perceived control over the outcome led to significantly larger FRN valence effects. To be consistent with current literature, effects of sense of control and expectations on reward positivity were examined through the analysis of average amplitude at the time of the FRN in difference waves (win – loss). Based on previous research, it was hypothesized that unexpected outcomes would lead to a larger reward positivity compared to expected outcomes (Holroyd et al., 2011). The results of this study supported this hypothesis as the amplitude of the difference wave was larger after unexpected outcomes in both tasks. Similarly and as hypothesized, a greater sense of control over the outcome led to larger reward positivity (i.e., larger positivity in the Time Estimation task). As the FRN peak analysis showed, the differences observed between

the tasks were not driven by the FRN size to one type of valence/expectedness of the outcome. Thus, greater investment in the task and unexpected outcomes led to a larger positivity at the time of the FRN. Greater positivity after unexpected outcomes supports the proposal that reward positivity reflects prediction error signal (Holroyd & Coles, 2002; Holroyd et al., 2008). If this is indeed the case, the results of this study show that greater investment (i.e., control over the outcome) leads to an increase in prediction error signal. Previous research has shown that the dopaminergic signal from ventral tegmental area (i.e., within basal ganglia) reflects salience of a stimulus rather than reward per se such that dopamine changes in the striatum (i.e., basal ganglia) reflect "excitement and arousal" (Stavarache, Pfaff, & Schober, 2009, pg. 337). Results of this study support this notion that the dopaminergic signal of prediction error, projected to ACC and measured at the scalp, reflects stimulus salience which increases with increasing cognitive investment at the time of the outcome.

Talmi, Atkinson and El-Deredy (2013) have proposed that the FRN is a marker for the salience of prediction errors in general rather than being reward-specific. Participants were asked to perform a task where the aversive stimulus was either monetary (a loss) or physical (pain), with high/low magnitude and expectedness (probability-based). For each type of trial, the outcome could either be delivered or omitted. The FRN was observed regardless of the modality of aversive outcome and was larger for 'no gain' and pain stimuli compared to 'win' and 'pain omission' outcomes. The FRN was also sensitive to the expectedness of the outcome such that unexpected stimuli in either modality were followed by a larger FRN amplitude compared to expected ones. Additionally, the effect of these factors on the reward positivity, observed at the time of the FRN in both

conditions, was examined. The difference in waveforms between 'reward-no reward' conditions was similar in topography and timing as the difference between 'no punishment-punishment' conditions. They suggested that the ACC activation at the time of the FRN reflects prediction error in general, such that any salient stimulus (e.g., omission of pain) elicits a prediction error regardless of reward value. Thus, the FRN and reward positivity reflect magnitude of the prediction error that is not necessarily based on rewarding stimuli only.

Between subject effects

Electrophysiological differences.

Having addressed what the FRN appears to reflect with respect to cognitive processes (i.e., its functional significance), we now turn to individual differences in terms of gambling behaviour. It was hypothesized that there will be group differences in the FRN measures, such that participants at risk for PG will not be sensitive to the sense-of-control manipulation (i.e., would have a similar pattern of results in the two tasks). It was assumed that individuals at risk for problem gambling behaviour would hold cognitive distortions regarding their ability to control the outcome, and thus would feel an equal sense of control in both tasks. This hypothesis was not supported, as both groups of participants showed a larger FRN-valence effect in the Time Estimation task compared to the Doors task. Furthermore, participants in the PG group did not report being more confident or more accurate in their predictions of the outcome in the Doors task compared to their nPG counterparts. Similarly, both groups of participants were equally aware of different levels of probabilities of reward in the Doors task and adjusted their expectations accordingly. Thus, the results of this study suggest that at-risk gamblers did

not differ in perception of control over the outcome or probability of rewards in a gambling context (i.e., the Doors task). Furthermore, due to the probabilistic nature of gambling activities, skill or strategy rarely increases chances of winning. Previous research has shown that at-risk/problem gamblers report higher levels of cognitive distortions regarding the role strategy and skill have on chance-based games (Johansson, et al, 2009). In our study, no one reported using a strategy in the Doors task, suggesting that none of the participants were under the impression that a strategy might increase one's ability to win. Thus, any cognitive distortions held by PG participants were not perceived to be relevant to the task and did not play a role at the time of outcome evaluation, explaining lack of support for the hypothesised results.

Although the two groups of participants were similar in their sensitivity to sense of control and expectation manipulations, the ACC response in each group differed based on the type of outcomes (i.e., win/loss). More specifically, for participants in the nPG group sense of control and expectations modulated the ACC response following losses, whereas in the PG group these effects were observed mostly following the ACC response to wins. Thus, individuals at risk for gambling behaviour (in contrast to those not at risk) showed altered ACC response following both rewards and punishments, such that they were more sensitive to characteristics of the rewarding outcomes and less sensitive to the characteristics of punishments. These results are consistent with previous research showing that problem gamblers have more activation of the ventral striatum (i.e., basal ganglia) in response to rewards of different magnitude compared to controls (van Holst et al., 2012). Similarly, other studies have shown that problem gamblers have higher activation of basal ganglia following near-wins and monetary rewards (Chase & Clark,

2010; Sescousse et al., 2013). The results of Study 2 can be interpreted as evidence for altered reward processing in individuals at-risk for problem gambling. As these individuals showed effects of both top-down and bottom-up influences on the ACC activity, it is likely that this altered reward processing can arise from changes in the response of subcortical areas as well as altered PFC functioning. This may help explain the diversity of factors (e.g., preference for reward type, cognitive distortions) leading to problem gambling behaviour.

It was originally expected that all participants would show FRN-valence effects (i.e., larger FRN following losses than wins) in both tasks. However, only participants in the PG group significantly differentiated between the valence of the outcomes in the Doors task. If the FRN reflects prediction an error signal based on salient stimuli, these results suggest that, in a gambling context, valence was a salient characteristic of outcomes to individuals at risk for problem gambling behaviour but not to individuals who were not at-risk. This interpretation would be consistent with previous research showing that contextual cues associated with addictive behaviour elicit urges to engage in the addictive behaviour (e.g., Kushner et al., 2007), which is reflected in the activity of the reward network (for a review of neural basis of addiction see Koob & Volkow, 2010). For example, increased activity of the PFC and ACC were observed in smokers during presentation of smoking cues (ashtray, lighter; Lee, Lim, Wiederhold, & Graham, 2005). Similarly, gambling cues (e.g., casino table) were shown to elicit greater activation of the PFC (ventromedial and dorsolateral) compared to neutral cues (Goudriaan et al., 2010). Furthermore, variation in the genes responsible for regulation of dopaminergic neurotransmission was shown to modulate the activation of the reward network in

response to smoking cues in smokers (McClernon, Hutchison, Rose, & Koznik, 2007). Taken together these findings suggest that individuals with addiction are more sensitive to stimuli related to their addiction (e.g., casino table, smoking) and that this reactivity is reflected in the reward network which is modulated by the functioning of the dopaminergic system.

If the FRN reflects a prediction error signal in response to salient outcomes, it would be expected that gambling contexts or cues would elicit more pronounced responses to stimuli in individuals with maladaptive gambling behaviour, compared to controls, by increasing the overall levels of arousal or excitement. The Doors task was designed to resemble a gambling context, such that the delivery of rewards was probabilistic and the outcomes seemed to depend on participants' choices (i.e., similar to a games of chance). The results of this study were consistent with the notion of FRN reflecting salient prediction errors such that individuals in the PG group were more sensitive to the valence of the outcomes, especially rewards, in the gambling task (i.e., Doors) compared to their nPG counterparts.

It was expected that individuals at risk for problem gambling behaviour would have an earlier FRN. The latency analysis was conducted primarily in order to replicate the findings of Oberg et al. (2011) who found that gamblers differentiated between the valence of the outcome earlier than non-gamblers. It was also hypothesised that FRN peak amplitude would be attenuated in the PG group, replicating the effects found by Torres et al. (2013). Neither of these hypotheses were supported, as there were no group differences in latency or size of the FRN. Although, inability to replicate previous findings could be due to the relatively low power of this study, it is also possible that the

relationships between gambling status and FRN are very small considering the FRN represents a neural response from one structure of the brain (i.e., ACC), whereas gambling behaviour is a product of multiple areas within a network. Furthermore, in both studies (i.e., Oberg et al., 2011; Torres et al., 2013), problem gamblers were identified using clinical criteria, whereas in our study PG group consisted of individuals identified as at-risk for problem gambling (i.e., our sample included participants with less severe gambling addiction). It is possible that the activity of the ACC does not vary gradually with increased levels of gambling behaviour, but instead problem gambling behaviour results from changes in the reward system (pre-existing or as a result of related behaviour, cognitions or environment) and that these changes are reflected in the FRN only when the behaviour becomes clinically maladaptive. However, results of this study suggest that the FRN can be used as a marker for the altered functioning of the reward network if the task is designed to have outcomes with different characteristics (e.g., expectedness). Individuals at risk for problem gambling behaviour show increased sensitivity to the characteristics of win outcomes compared to not-at-risk individuals. Thus, maladaptive gambling behaviour is marked by higher sensitivity to rewards that is reflected in the change in ACC activity (i.e., comparisons of FRN effects) rather than absolute magnitude of the response in general (i.e., size of the FRN).

Previous research has shown that severity of problem gambling related to the activity of the reward network, but these relationships were examined mostly in a clinical sample of problem gamblers (Mield et al., 2012; Oberg et al., 2011). Further research is needed to examine if the sensitivity of the reward network changes gradually as individuals *develop* gambling addictions rather than with increased severity of an established

addiction, and if these changes are reflected in the activity of the ACC in a similar manner (i.e., gradual change). If this is indeed the case, then analysis of FRN responses could aid in identifying individuals at risk for pathological gambling. However, the results of our study suggest that changes in FRN response can be observed only through comparisons of reward outcomes (e.g., expected versus unexpected) in individuals who are at-risk for problem gambling. Otherwise, the activity of ACC, as reflected in the FRN size and timing, is altered only after gambling behaviour becomes clinically maladaptive as neither of the measures of gambling severity (i.e., PGSI scores; frequency of gambling behaviour) or measures of individual differences, that differentiated between the groups, were related to the FRN amplitude of latency. However, the FRN following unexpected losses in the gambling context (i.e., in the Doors task) was related to the diversity of gambling activities engaged in by the individual such that larger ACC response was associated with fewer gambling activities. As at-risk participants also showed lower sensitivity of the FRN to the characteristics of loss outcomes observed in the PG group it is possible that as an individual engages in more gambling activities, the response of the reward system changes from being loss-oriented (i.e., as in nPG group) to gain-oriented (i.e., as was seen in the PG group).

Problem Gambling and Personality

Examination of personality differences between the two groups revealed that individuals at-risk for problem gambling reported higher levels of Emotionality and lower levels of Conscientiousness compared to their not at-risk counterparts. Furthermore, lower levels of Conscientiousness, Honesty/Humility and Agreeableness were related to higher frequency of gambling behaviour, but only Agreeableness

uniquely predicted gambling frequency. These relationships were not mediated by or correlated with any of the FRN measures, suggesting that personality plays a role in development/maintenance of PG behaviour that is distinct from the cortical response to rewards and punishments.

There has been only one study to date examining the relationships between HEXACO personality factors and problem gambling. Consistent with the results of this study, Twigger (2010) reported that high-risk gamblers reported lower levels of Conscientiousness and Honesty/Humility. Lower levels of these traits were also shown to be associated with more willingness to take risks and increased perception of benefits following risk-taking (Weller & Tikir, 2011). A later study revealed that Honesty/Humility was negatively correlated with risk-taking regardless of valence of the outcome (i.e., to achieve wins or avoid losses), whereas lower Conscientiousness was related to greater risk taking to achieve gains (Weller & Thulin, 2012). Thus, the results of this study are consistent with previous literature such that Conscientiousness levels differentiated between individuals at-risk and not-at-risk for maladaptive gambling behaviour.

Although there was no significant difference in Honesty/Humility between the groups, PG group reported slightly lower scores on this trait compared to nPG (i.e., the relationship was in the right direction). It is possible that this difference was not significant due to relatively small sample size. In this study, Honesty/Humility was related to the frequency of gambling suggesting that lower levels of this trait can exacerbate maladaptive gambling behaviour. This interpretation is consistent with theoretical construct of Honesty/Humility, such that individuals low in this trait desire to

have money and to have more than others (Lee & Ashton, 2012) and, thus, are driven to engage in gambling behaviour more often. More specifically, the combination of low Conscientiousness and low Honesty/Humility has been interpreted as a risk factor for development of problem gambling as these individuals are greatly motivated by monetary gains and have trouble controlling own impulses (Lee & Ashton, 2012).

Further support for the role of personality traits in problem gambling comes from research using the Big Five Factor model (Goldberg, 1990; McCrae and Costa, 1999), which are very similar to the constructs measured by the HEXACO. For example, Conscientiousness and Agreeableness factors are similar to those measured by the HEXACO model, and Neuroticism highly overlaps with the domain of Emotionality in the HEXACO model. Problem gamblers consistently report lower levels of Conscientiousness, Agreeableness and Neuroticism (MacLaren et al., 2011; Reid et al., 2011; Hwang et al., 2012) and combination of these characteristics were also shown to be predictive of treatment compliance (Ramos-Grille et al., 2013). More specifically, individuals who score low on domains of Neuroticism and Conscientiousness are more likely to relapse after treatment, while those who score low on Agreeableness in addition to the other two domains are more likely to drop out of treatment (Ramos-Grille et al., 2013). Individuals with low levels of Agreeableness are stubborn, ready to take offence, get angry fast when provoked and have trouble forgiving past injustices (Lee & Ashton, 2012). It is then not surprising that individuals exhibiting these characteristics are more likely to drop-out of treatment. In this study, lower levels of Agreeableness were predictive of higher frequency of gambling and greater variety of gambling activities engaged in during the past year. If individuals low in Agreeableness readily assume that

someone is taking advantage of them (e.g., a casino) and have trouble letting go of losses, it is reasonable to assume that they will try to win their money back more often (i.e., gamble more frequently) and switch from one type of gambling activity to another often to avoid supposedly 'rigged' games.

Constructs of Emotionality and Neuroticism measure characteristics such as worry, desire to share concerns with others, and anxiety in stressful situations, among other things (Lee & Ashton, 2012). High levels of Neuroticism have been associated with development of depression and other mental health difficulties (e.g., Merino, Ferrerio, & Senra, 2013; Zakiee, Rostami, & Kamasi, 2014). Additionally, individuals low in Conscientiousness and high in Neuroticism have been shown to be more vulnerable to stress and have maladaptive coping strategies (Vollarth & Torgersen, 2000; Boyes & French, 2012). Conscientiousness, on the other hand, taps into one's ability to delay gratification, control desires, goal-directedness and need for accuracy and precision (Lee & Ashton, 2012). In other words, people high on Conscientiousness have good self-regulating abilities. Problem gamblers have been consistently shown to score lower in this domain compared to healthy controls (e.g., Hwang et al., 2012), suggesting that these individuals have trouble regulating desires and affect.

Individuals at-risk for problem gambling seem to have lower thresholds for stressful events, have poor coping skills and impaired self-regulation abilities. In fact, problem gamblers who report gambling to 'escape' stressful situations have been shown to score higher on Neuroticism subscales compared to those who gamble for other reasons (Reid et al., 2011). Thus, previous research and results of the current study suggest that in individuals low in Conscientiousness and high in

Neuroticism/Emotionality, problem gambling behaviour is a product of maladaptive effort to regulate affect and deal with stress in one's life.

Interestingly, Emotionality/Neuroticism did not relate to the frequency of gambling behaviour, suggesting that low scores in this domain are risk-factors for maladaptive gambling behaviour but do not play a role in severity of such behaviour. This notion is consistent with the interpretation that PG develops due to poor coping skills and reactions to stressors: if these skills are absent individuals might turn to gambling, but the degree of such deficits play no role in the severity of the problem behaviour. Conscientiousness, on the other hand, reflects one's ability to control impulses and desires, so lower levels of self-regulation ability could lead to greater severity of maladaptive behaviour.

In summary, the results of this study suggest that individuals with poor coping skills and impaired ability to self-regulate turn to gambling as a strategy to cope with stressful events. This maladaptive gambling behaviour is further exacerbated by beliefs in entitlement, desires to get rich quick (i.e., low Honesty/Humility) and inability to let go of negative events (i.e., low Agreeableness). As none of these traits were related to EEG measures, one possibility is that the effects of these risk factors operate separately from any changes in the functioning of the reward system in processing of decision outcomes. It may also be the case that the neurobiological factors moderate or enable the severity of problem gambling. Unfortunately, testing this possibility will need to await a much larger study combining the personality and ERP measures.

Conclusions

In summary, the results of this study suggest that FRN is sensitive to the salient characteristics of a stimulus as defined by the task goals, such that more salient characteristics (e.g., loss or unexpectedness) lead to larger FRN amplitude. Outcomes in the Time Estimation task and unexpected outcomes in general elicited a larger positivity at the time of the FRN, which is also consistent with the idea of 'salience' positivity proposed by Talmi et al. (2013), such that salient stimulus characteristics elicit a positivity after stimulus presentation. Participants at risk for PG were sensitive to the valence of the outcome in the Doors task, whereas their nPG counterparts were not, suggesting that gambling contexts (i.e., tasks/games of chance) increase the sensitivity of the reward system to valence of the outcome in individuals at risk for problem gambling behaviour. Furthermore, results of this study support the hypothesis that maladaptive gambling behaviour leads to an increased sensitivity of the reward network to reward characteristics and a decreased response to different loss outcomes. Thus, the results of this study support the hypothesis that previous history of maladaptive gambling behaviour is related to altered responses of the reward network. Furthermore, as the results of this study did not replicate previous research using pathological gamblers (i.e., defined using clinical measures), it is likely that the FRN size and latency does not change gradually with increasing risk of maladaptive behaviour. Instead, changes in ACC activity reflected by the FRN in general can be observed only after behaviour becomes clinically maladaptive or through comparison between different types of gain/loss outcomes.

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General Discussion

The studies in this dissertation were conducted in order to test a model of FRN generation which includes modulating inputs from the medial PFC on the activity of the ACC. In the proposed model, these projections (i.e., top-down) carry information regarding subjective characteristics of the stimulus/task (e.g., relevance to current goals). Relatively low level (objective) stimulus characteristics (e.g., valence) are processed in the subcortical areas (basal ganglia); this information is then projected to the ACC (i.e., bottom-up input). Clear dissociation between the effects of these stimulus/task characteristics (i.e., objective vs. subjective) at the level of the FRN was proposed to support a model of direct relay of *subjective* information from the medial PFC to the ACC (Figure 4.1).

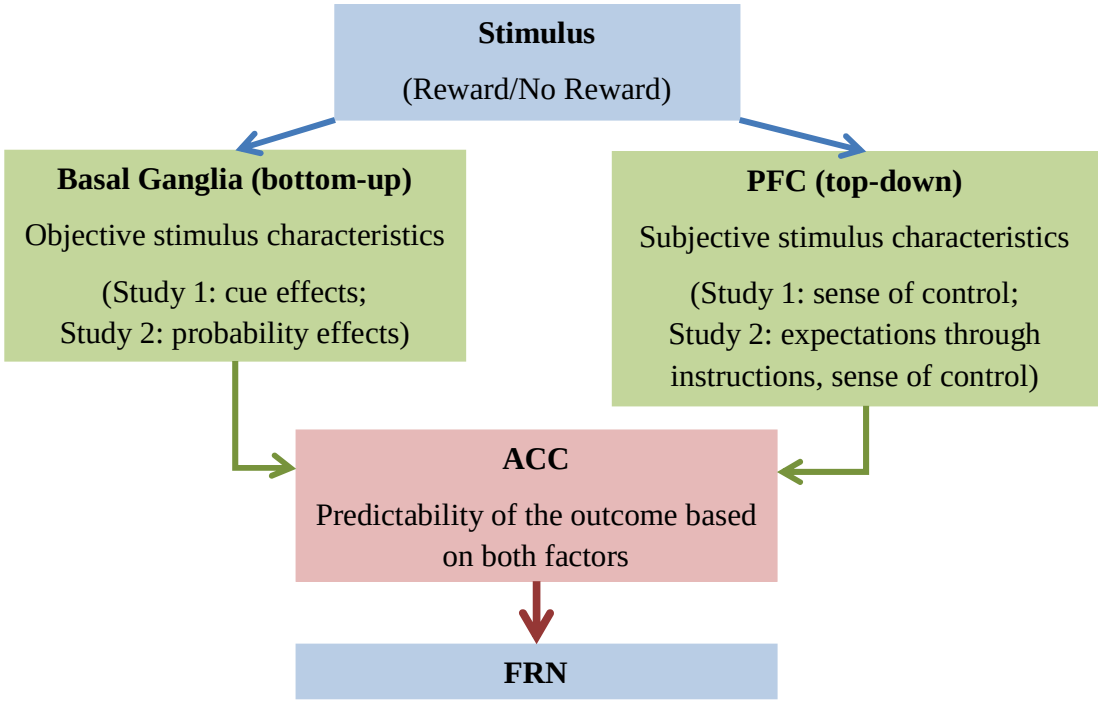

Figure 4.1. Schematic representation of the model of FRN generation that was tested in the studies in the dissertation research.

More specifically, it was proposed that complex cognitive states, such as perception of sense of control over the task outcome, will influence FRN activity through top-down projections from frontal cortical areas to the ACC. Simpler characteristics such as valence of the stimulus or probability of a certain outcome were proposed to influence ACC activity through bottom-up projections from the basal ganglia. In Study 1 this model was examined by comparing the effects of presence or absence of informative cues (bottom-up) and three levels of (top-down) perceived feeling of control over the outcome. In Study 2, sense of control was manipulated by the type of task (top-down) and expectations were based on probability (bottom-up) or instructions (top-down). Thus, effects of projections from both basal ganglia and PFC to ACC were indirectly examined in both studies.

Effects of cue

Presence of informative cues attenuated the FRN-valence response as was predicted. In Study 1, half of the tasks performed by participants included an informative cue. Previous research has shown that presence of informative cues affects FRN amplitude at the time of outcome presentation (Holroyd, Krigloson, & Lee, 2011; Xu et al., 2011). Results of Study 1 showed that in gambling paradigms (i.e., Some-Control tasks), presence of an informative cue attenuated FRN amplitude elicited by the presentation of outcomes on each trial (no cue: $p\eta^2 = .192$; cue: $p\eta^2 = .405$). Research on reward processing in the nAcb shows that cues associated with rewards elicit a similar dopaminergic response as the presentation of the reward (Knutson, Adams, Fong, & Hommer, 2001), and in some cases attenuates it (Holroyd et al., 2011). If the valence information present in the informative cues elicited a similar response in the nAcb (i.e.,

in the basal ganglia) as was observed in Shultz's work, the dopaminergic signal from the basal ganglia would also be attenuated. Thus, the hypothesis that the presence of stimulus characteristics that can be coded in the basal ganglia will attenuate the response of the FRN was supported. The effects of the cue further support the theory of dopaminergic nature of the FRN generation proposed by Holroyd and Coles (2002).

Broyd et al. (2012) examined the effects of cue valence (gain or loss) on the P3 amplitude associated with the cue and CNV that followed the cue. The CNV amplitude is a reflection of anticipatory response to the stimuli (i.e., preparation for action), and it has been shown to be attenuated by lower levels of dopamine in the brain (for review see Brunia, van Boxtel, & Böcker, 2012; Linssen et al., 2011). This component was also shown to vary in amplitude in response to the attentional demands of the task, arousal levels and relate to behavioural performance (Tecce, 1972; Funderud et al., 2012; Schevernels et al., 2014). Thus, the CNV is often interpreted as a marker for motor and attentional preparation to respond. Broyd et al. (2012) found that the valence of the cue did not affect the CNV, indicating that this measure was not sensitive to any differences in arousal/attention allocation needs resulting from positive versus negative cues, if there were any. The valence of cues was dissociated in another component; P3 amplitude was larger following gain cues. Unfortunately, the N2 components elicited by the cue were not reported, so it is unclear whether the ACC response to the cue was similar to that observed after outcomes. If these responses were similar, that would provide further support for the modulation of ACC activity to reward information in general. Nevertheless, Broyd et al.'s results are indicative that the valence of the cue is processed at the time of its presentation (i.e., P3 effects) and does not modulate the anticipatory

activity EEG measures (i.e., CNV). Thus, the effects of the cue on the FRN observed at the time of presentation of the outcome are not due to differential activity during the anticipatory phase of the task.

Given that any activity at the time of the cue did not influence the components observed during the anticipatory period, it is likely that whatever perturbations in the system caused by the cue were short lived. However, there are effects at the time of the FRN, and this suggests the cue-information might change the baseline activation of the nAcb that then affects the feedback-ERP response. If presence of the cues caused a change in activity in the nAcb, these effects would not be observed in our EEG signal because the subcortical areas do not project a signal to the scalp. However, change in nAcb activity can influence the dopaminergic signal projected to the ACC at the time of the outcome and in turn, affect the FRN. Consistent with predictions of the proposed model, the results of this study support the presence of bottom-up modulation of the ACC at the time of the FRN.

Effects of sense of control

The results of Study 1 suggest that the manipulation of sense of control did not affect the FRN as expected. Levels of sense of control were differentiated such that when participants knew their outcome depended only partially on their response (Some-Control), the FRN-valence effects were most reliable. Thus, any effects of control over the outcome should be interpreted with caution. As there were no other effects in terms of sense of control on the FRN amplitude, the results of the study are inconsistent with predictions based on the proposed model. It was hypothesized that greater sense of control would increase the valence effects observed in the FRN as individuals would be

more invested in the outcome. This hypothesis was based on previous research showing that diminished sense of responsibility attenuates the FRN valence in a similar fashion (Li et al., 2011) as was seen in tasks where participants were not actively making decisions (Yeung, Holroyd, & Cohen, 2005; Bismark, Hajcak, Whitworth, & Allen, 2011). Feeling in control over the outcome is a complex cognitive construct and, thus, it was assumed it would be represented by the top-down projections from the frontal cortices to the ACC. There was no consistent influence of perception of control as defined by the manipulations on the FRN and, thus, the hypothesis of top-down modulation of ACC at the time of the FRN was not supported.

There was some support for the effects of sense of control on the FRN in Study 2, such that FRN-valence effects were observed to be larger in the Time Estimation task. However, as there were no valence effects observed in the Doors task in the nPG group, it is hard to conclude that the difference in the perceived sense of control alone caused an increase in the valence effects. As previous research suggests that non-gamblers should differentiate between the valence of the outcome in the Doors task (Hajcak, Moser, Holroyd, & Simons, 2007), it is possible that the combination of the two tasks led participants in the nPG to discount the valence of the outcome and process the outcomes based on its expectation value. The tasks were different in the levels of perceived sense of control over the outcome as well as emphasis on prediction of the outcome. More specifically, participants had greater sense of control over the outcome in the Time Estimation task, but were not asked to explicitly predict the outcomes as was done in the Doors task. As no consistent FRN valence effects were observed in the Doors task in this

group, it is hard to be sure that the observed patterns were due to the difference in levels of control rather than emphasis on other stimulus characteristics (i.e., expectedness).

The effects of sense of control were much clearer in the PG group, who showed FRN-valence effects in both tasks such that FRN-valence effects observed in the Doors task ($p\eta^2$ = .234) were smaller than those observed in the Time Estimation ask ($p\eta^2$ = .326). Thus, the hypothesis regarding higher perceived control over the outcome increasing the FRN-valence effects was supported. The results of this study are consistent with previous literature (Li et al., 2011; Bismark et al., 2011), and show that modulation of the FRN can be achieved by changing the participant's *perception* of control in the task. Greater perception of control over the outcome leads to greater cognitive investment in the outcome, thus increasing the sensitivity of the ACC to the valence of the outcome.

Reconciling Study 1 and Study 2

According to the proposed model, an increase in the level of perceived control over the outcome should have increased the FRN-valence effects through top-down projections to the ACC from the PFC. This hypothesis was supported by the pattern of results observed in Study 2 and not in Study 1. However, lack of consistent valence effects in all tasks and larger FRNs in the intermediate condition (i.e., Some-Control) could be a sign that the manipulation of sense of control in Study 1 was not effective, which would explain the lack of effects in the expected direction (i.e., FRNs should be largest in Full-Control, followed by Some and No-Control conditions). Further research is needed to identify an effective way to manipulate the sense of control in order to draw more definite conclusions about its effects on the FRN amplitude. The results of Study 2

supported the hypothesis for top-down modulation of ACC activity, such that perception of control over the outcome led to an increased FRN-valence effect. This effect was more pronounced in a group of at-risk problem gamblers compared to not at-risk individuals. If the PFC directly modulates ACC activity at the time of the FRN, the effects of task characteristics that would modulate this activity (e.g., sense of control) should be dissociable from objective stimulus characteristics (e.g., valence) and, thus, be easily observable at the time of the FRN. The analysis conducted in this dissertation shows that these effects are small (i.e., nPG group) but can be amplified in certain populations (i.e., in the PG group), suggesting that these influences are processed through a non-direct pathway (i.e., through other structures such as basal ganglia) rather than through direct links with PFC.

Effects of expectations

According to the proposed model, any effects of expectations on the FRN were to be interpreted as activations from bottom-up projections if judgements were based on probabilities; on the other hand, if expectations were modulated through instructions (i.e., through a change in 'cognitive set'), influences on the FRN were to be interpreted as top-down modulations of ACC activity. These effects were examined in Study 2; judgements in the Doors task were based on probability of the trial and judgements in the Time Estimation task were based on the type of the 'cue'. Significant effects of expectations were observed in the Doors task, where unexpected stimuli led to a larger FRN amplitude. Thus, only the hypothesis about bottom-up influences on the ACC activity was supported.

There were no significant differences in the FRN based on the expectedness of the stimulus in the Time Estimation task. Although it is possible that the manipulation of expectations did not work in the Time Estimation task, the self-reported ratings obtained in Study 2 show that participants did try harder on the 'hard' trials 'than on the 'easy' trials in the Time Estimation task, suggesting that the instructional manipulation in the Time Estimation task led participants to have lower expectations for success on 'hard' trial. So it is more likely that manipulation of expectations through instructions had a delayed effect on behaviour (i.e., after an initial prediction error signal was signalled by the FRN) and, thus the effects were reflected in self-report measures but not the FRN. If this is the case, then this manipulation would not have an influence on the FRN response as the information from higher cortical areas responsible for processing cognitive information (e.g., "green cue means an easy trial, so I expect to win") would be integrated into the system at a later stage (e.g., during re-evaluation of behaviour). Thus, the lack of expectation effects on the FRN in either group suggests that the effect of this manipulation, if any, was small and the hypothesis of cognitive factors directly influencing the ACC activity through the medial PFC (top-down) projections was not supported.

Re-evaluation of the proposed model

The studies in this dissertation were conducted to test the predictions based on the proposed model of FRN generation and modulation of ACC activity. The model proposed a division of stimulus characteristics into subjective and objective factors, which are coded in the medial PFC and basal ganglia, respectively. The latter part of the model was based on the reinforcement learning theory of FRN/ERN generation (Holroyd

& Coles, 2002) and neurobiological evidence from research on response of structures in the basal ganglia to reward (e.g., nAcb; Schultz & Dickinson, 2000). These influences were tested by examining the effects of valenced cues (Study 1) and probability-based expectations (Study 2: Doors task) on the FRN measures. There was consistent evidence for proposed bottom-up modulations of ACC activity such that informative cues attenuated the FRN-valence effect and unexpected outcomes elicited larger FRN amplitude. As these factors could be dissociated from the manipulation of subjective stimulus/task characteristics in each study, it was concluded that this information is indeed coded in subcortical areas and then projected to the ACC.

Previous research has shown that complex cognitive constructs such as cognitive state during the outcome presentation (Yang, Gu, Tang, & Luo, 2013), sense of responsibility over the outcome (Li et al., 2010), trustworthiness of a partner (Long, Jiang, & Zhou, 2012) and personality (Santesso & Segalowitz, 2009; Segalowitz & Dywan, 2009; Santesso, Dzyundzyak, & Segalowitz, 2011) influence the FRN elicited by the outcomes in the tasks. It was assumed that such complex constructs arise form integration of information across a number of cortical areas, which then project to frontal cortices for modulation of behavioural response. Medial PFC has been shown to play a role in updating the incentive value of stimuli, generation of expectancies and selection of goals (Roberts & Parkinson, 2006). Maturation of medial PFC has been associated with improved ability to regulate behaviour (e.g., Luna et al, 2004; for a review see Ernst, Romeo, & Andersen, 2009) and damage to this area has been shown to result in inappropriate and uninhibited behaviour (Spinella & Miley, 2004; Chan et al., 2005). Furthermore, medial PFC has been shown to be sensitive to subjective value of the

stimulus (O'Doherty & Dolan, 2006; Kheramin et al, 2004; Kable & Glimcher, 2007) and have direct projections to the ACC and nAcb (Vogt & Pandya, 1987; Devinsky, Morrell, & Vogt, 1995). Thus, it was proposed that projections from the medial PFC to the ACC carry information regarding the subjective value of the stimulus given the task goals and structure. If this is indeed the case, then subjective characteristics of the stimulus should be dissociable at the level of ACC activity (i.e., effects of objective and subjective stimulus characteristics are additive), and would be reflected in the FRN measures.

This hypothesis was tested via tasks varying in sense of control over the outcome (Study 1 and Study 2) as well as manipulation of expectations through instructions (Study 2). Sense of control manipulation did not support the hypothesis of top-down inputs in Study 1 as FRN did not consistently increase with increasing sense of control (i.e., No-Control < Some-Control < Full-Control). In Study 2, increased perception of control did increase FRN valence effects as participants showed larger effect sizes in the Door task compared to Time Estimation. However, there were no effects of expectations in the Time Estimation task (manipulated through instructions) in either of the groups. Thus, the evidence for top-down modulations of ACC activity was not consistent and only partially supported the proposed model. These manipulations and measures provided an indirect way to test the proposed model, and thus only consistent evidence of additive effects at the time of the FRN was considered sufficient to support the model.

Lack of such consistent support for the hypothesis based on top-down pathways of information suggests it is more likely that information about subjective characteristics is used to change the baseline levels of activity in lower cortical areas early in the task. In

terms of the model, information regarding subjective factors is relayed from the medial PFC directly to the subcortical areas (i.e., basal ganglia), changing the baseline activity of these areas. The output signal of subcortical areas, a result of interactions between objective and subjective characteristics, is then projected to the ACC. Thus, the two models (original and updated) are similar in that ACC receives information regarding both subjective and objective stimulus characteristics. In the originally proposed model ACC was the area where these two signals were reconciled, which was marked by the generated FRN. In the updated model, subjective and objective characteristics are combined at the level of basal ganglia, leaving open the question of what part of this information is projected to the ACC and reflected in the FRN.

Functional significance of the FRN.

Current research suggests that the FRN reflects reward prediction error, such that negative prediction errors (i.e., when predicted reward was omitted) elicit a negativity following the presentation of the outcome and positive prediction errors (i.e., unpredicted rewards) lead to a reward positivity (Holroyd et al., 2011). Most of previous research done on the FRN concentrated on the factors affecting the FRN-valence effects by manipulating frequency, probability and magnitude of the rewards (e.g., San Martin et al., 2010). FRN has also been shown to be modulated by perceptual characteristics of the stimulus (e.g., similar/dissimilar: Donkers & van Boxtel, 2005; Gehring, Liu, Orr & Carp, 2012). The latter findings would be consistent with the theory that ACC is sensitive to conflicts between motor responses that arise in the system (Yeung, Botvinick, & Cohen, 2004). The main difference between the two theories, is that the conflict–model suggests that mismatch in possible behavioural responses modulates the

FRN, whereas in the reinforcement learning theory, mismatch between the predicted and obtained outcomes modulates the FRN. In other words, either mismatch in future behaviour (conflict) or obtained stimuli (reinforcement learning) affect the FRN. Emric et al. (2008) have shown that ACC cells in primates generates local field potentials in response to errors and feedback, but not to conflict-related signals (i.e., choice between conflicting eye-gaze responses). Furthermore, as the FRN has been observed even in the absence of motor outputs (e.g., Yeung et al., 2005), it is unlikely that FRN is a marker for conflict between competing motor signals.

Reinforcement learning theory suggests that the FRN is a marker for prediction error signal occurring in the subcortical areas. These prediction errors can be based either on the incentive value of the stimulus (i.e., valence, magnitude) or other stimulus characteristic (e.g., context – win/loss block). Talmi and colleagues (2013) showed that similar FRN-valence effects can be elicited by monetary (win/loss) and physical (pain/no pain) outcomes. Positive outcomes (monetary win/no pain) led to smaller FRN amplitude compared to negative outcomes (monetary loss/pain) regardless of the modality of presentation. The authors have suggested that FRN represents a prediction error based on salient stimuli and is not specific to rewards.

Another study showed that the ACC activity was sensitive to changes in stimulus characteristics in response to changes in task demands (van Noordt, Desjardins, & Segalowitz, 2012). Participants were asked to complete a version of a Go/Nogo task, where two stimulus characteristic were manipulated: colour of the fixation cross and of the box surrounding the fixation. Nogo trials occurred when the colour of the fixation changed from white to black. The colour of the fixation box signified the type of trial,

such that two of the colours coded for a *certain* block (i.e., zero Nogo trials present) and the other two alerted the participant that this block contained some Nogo trials (*possible* block). Participants were informed of the colour-block (certain/possible) associations prior to starting the task. The analysis of the data showed that the ACC was sensitive to the changes of the box colours, regardless of what type of block it would represent (i.e., safe vs. Nogo block). More specifically, this activation was observed even when the block-type did not change (i.e., *possible* to *possibl*e blocks). These results further support the notion that the ACC is responsive to changes in stimuli that signal the need for attentional control (i.e., salient characteristics).

Some of the results outlined in this dissertation research were also consistent with the proposal that FRN reflects prediction errors based on salient stimulus characteristics. In Study 2, healthy individuals showed a larger FRN response to *unexpected* outcomes in the Doors task and *loss* outcomes in the Time Estimation task. The expectedness of the outcome was emphasized in the Doors task by explicitly asking participants to predict the outcome. Thus, congruency between predicted and obtained outcomes was evaluated at the time of outcome presentation (i.e., "Was I right or wrong?"), which was reflected in the FRN amplitude. On the other hand, participants were under the impression that accurate responses in the Time Estimation task would lead to positive outcomes. In this task, valence of the outcome could be used to improve future performance and maximize winnings, whereas congruency with expectations based on trial type (i.e., easy vs. hard) would not provide further information regarding improvement of performance. Therefore, FRN amplitude reflected only the distinction between valence of the outcome (i.e., loss – too slow/too fast vs. win – on time).

Currently, FRNs generated by the ACC are interpreted in light of reinforcement learning theory such that ACC activity is a response to reward prediction error signal from subcortical areas (Holroyd & Coles, 2002; Holroyd, Pakzad-Vaezi, & Krigolson, 2008). The results of this dissertation research (Study 2) suggest that the ACC activity is modulated by the magnitude of prediction errors based on salient characteristics of the stimuli rather than reward specific characteristics. Although the hypothesis of projections from the medial PFC modulating the ACC activity was only partially supported, cognitive constructs and states have been previously shown to modulate ACC response to outcomes (e.g., Yang et al., 2013). Thus, it is likely that this information (i.e., subjective factors) is integrated in the dopaminergic response of subcortical areas prior to its relay to the ACC, possibly through changes in the baseline activity of the basal ganglia. Furthermore, individuals at risk for problem gambling were shown to be responsive to the manipulation of control at the level of the FRN, suggesting that this information was integrated in the dopaminergic response of the reward system. As medial PFC has direct connections to nAcb and ventral stratum, it is possible for this information to be processed in cortical areas and then relayed to the subcortex bypassing the ACC. Prediction errors would be generated based on the discrepancy between previous experience/goals (i.e., medial PFC information) and objective outcomes (i.e., basal ganglia). Thus, the FRN reflects the relative degree of these prediction errors based on salient stimulus characteristics (e.g., valence, expectedness), where saliency is determined by stimulus characteristics, task goals and cognitive state at the time of feedback presentation. In other words, activity of the ACC is modulated by stimulus characteristics that are important for future behavioural adjustment (i.e., salient).

Theoretically, this signal of 'something important has happened' can then be relayed to the frontal cortices for updating of goals and expectations.

This reinterpretation of the functional significance of the FRN is consistent with a relatively recent model of reinforcement learning, the predicted response-outcome (PRO) model, proposed by Alexander and Brown (2010). In this model, activity of the neurons in the medial PFC codes for predicted outcomes based on probability and timing of the outcome. If the predicted outcome occurs these neurons are then inhibited, and if predicted outcome fails to occur this activity increases until it reaches its maximum, thus coding for omitted outcomes. In the PRO model, responsivity of the ACC to stimuli is viewed as part of a larger medial PFC response (i.e., the function of each structure in predicting responses is not specified, e.g., Alexander & Brown, 2011). In this dissertation functions of medial PFC and ACC were considered to be separable, such that medial PFC is responsible for relaying information about subjective stimulus characteristics to the basal ganglia, which then projects this signal to the ACC. Results of this dissertation research suggest that the FRN is a marker for a prediction error signal based on the most salient stimulus characteristics. If we assume that the assumption of the medial PFC 'learning to anticipate the value of actions' (Alexander & Brow, 2011, pg 1338) made in the PRO model is correct, then it is plausible to assume that medial PFC should receive a signal regarding the accuracy of these predictions. Results of this dissertation research suggest that the FRN is a marker for this process, such that only prediction errors regarding the outcomes of the most salient (i.e., important for future improvement of

performance) characteristics of the outcome are relayed (Figure 4.2).

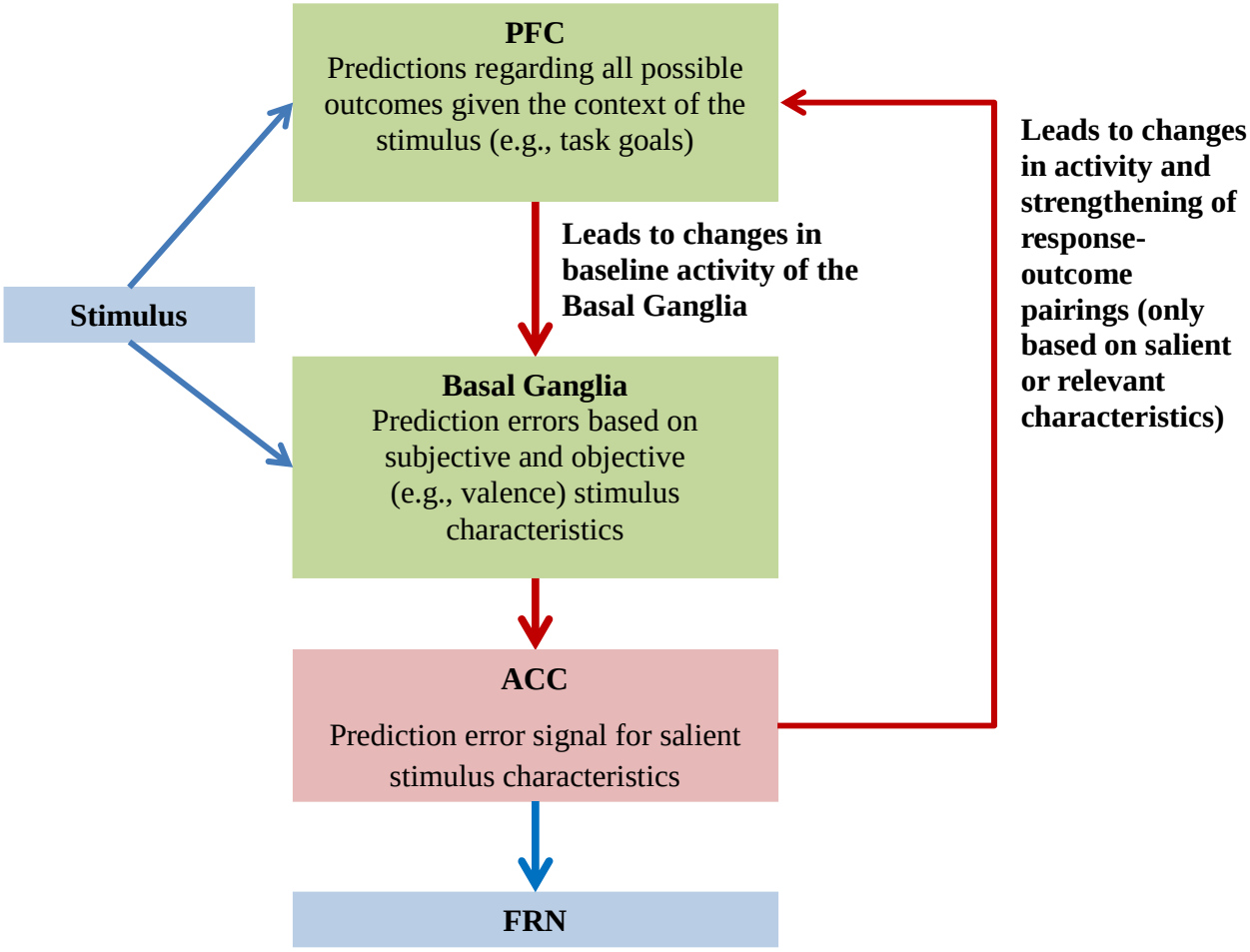

Figure 4.2. Schematic representation of sequence of events in the reinforcement learning pathway.

In other words, when feedback is presented, objective stimulus characteristics are processed by the basal ganglia, baseline activity of which is modulated by the information regarding task goals and subjective factors (e.g., cognitive state) projected from the cortical areas. Dopamine concentration within the basal ganglia is then either increased (i.e., reward) or decreased (i.e., no reward) depending on the outcome (i.e., objective characteristics). These changes in dopamine levels lead to changes in the baseline activity of the ACC, thus reflecting a summary of the prediction errors

signalling errors (i.e., only for salient stimulus characteristics). This signal is then projected to the medial PFC, where it can inhibit its activation if the response is consistent with prediction, or it can further increase activation if the outcome was unpredicted, training the network to formulate better predictions and allowing the organism to learn from previous experience. Thus, the reinterpretation of the functional significance of the FRN as a marker of prediction errors for salient stimulus characteristics is consistent with current models of reinforcement learning.

Implications and Future Directions

Research conducted for this dissertation suggests that FRN reflects prediction errors based on salient stimulus characteristics that are identified by the system as a function of the context (e.g., gambling related context), cognitive set (e.g., sense of control) and individual differences (e.g., personality). For example, to an individual reporting high levels of harm avoidance (Person A) losses might be equally salient in any context, whereas to someone with high levels of sensation seeking (Person B) all outcomes including losses would be more salient in arousing situations (e.g., gambling). In this case, Person A's FRNs will not differentiate between contexts but Person B's FRNs will vary depending on the context such that FRNs will vary with stimulus characteristics more in the arousing contexts.

Research shows that the brain changes with experience such that stimuli or characteristics that stand out in our environment (i.e., considered salient) are defined by our previous experiences. For example, individual with addictions show greater arousal in contexts with stimuli that are linked to their addictions (e.g., slot machines or casinos for problem gamblers) suggesting that these stimuli are more salient (e.g., Lee, Lim,

Wiederhold, & Graham, 2005; Kushner et al., 2007). Individuals at risk for PG showed less differentiation between the contexts of loss outcomes than not-at-risk controls, suggesting that losses are less salient to persons with maladaptive gambling behaviour. Interestingly, these individuals did not fail to differentiate between the two tasks, but this differentiation was observed only in their response to wins. Thus, the reward system was responsive to all stimulus characteristics but its 'focus' had switched from a loss- to a win-orientation. Given that experiences can lead to changes in the brain, it is unclear if these changes in the 'focus' of the reward system from negative outcomes to positive ones are a result of extensive gambling experiences or if these neurological differences are a risk-factor for development of problem gambling. In this dissertation FRN measures were not related to severity of gambling; however, other studies have shown such differences (by Oberg, Christine & Tata, 2011; Kreussel et al., 2013; Torres et al., 2013). Thus, it is possible that responsiveness of the reward system changes further as addiction develops. However, it is also possible that more severe gambling behaviour is a consequence of the functioning of the reward system. Only a longitudinal study examining change in neurological responses with development of problem gambling behaviour can address this issue.

Regardless of the direction of effects, it is clear that persons with maladaptive gambling behaviour show altered responses of the reward system compared to not-at-risk individuals. Once these responses are quantified and can be predicted, they can serve as markers for addiction risk-factors. Currently much more research on the topic is needed to get the field to this point, but results of this dissertation suggest that altered FRN responses account for unique variance in the changes linked to PG and this variance is

not shared with measures of variability in personality. Thus electrophysiological measures provide another piece of the puzzle, unique from effects of personality, which might bring us closer to understanding this type of behavioural addiction.

Although we do not fully understand the mechanism behind the development of addictions, every piece of the puzzle provides us with another way to help individuals overcome such behaviour. For example, research has shown that pathological gamblers hold a number of cognitive distortions and at least some of these individuals use gambling as a coping mechanism. Currently, it is still unclear why some people turn to gambling as means of coping rather than any other activities; however, given the nature of the relationship, it is possible that teaching recovering problem gamblers alternative coping strategies can prevent relapsing. Similarly, it has been shown that experiences and cognitions can change the responses of the reward system (e.g., cognitive reframing can attenuate FRN response; Yang et al., 2013). It is possible that teaching individuals to actively concentrate on losses and not wins in gambling situations might make the system to be more loss-focused (i.e., train the system to treat losses as more salient). Similar effects might already be achieved through cognitive-behaviour therapy which addresses cognitive distortions that are often held by problem gamblers, as such cognitions might be a by-product of reward-oriented state of the system. Much more research is needed to examine if such treatments would be effective and whether recovery process is reflected in electrophysiological measures.

It has also been proposed that there are several types of problem gamblers but there is no research examining potential differences between different types of gamblers and functioning of the reward system. In this study changes in the electrophysiological

responses did not explain the relationship between individuals' gambling behaviour and personality. If measures of responsivity of the reward system account for variance unique from personality and other cognitive constructs, it is possible that they can also help differentiate between types of PG and provide better tools for personalizing prevention and treatment strategies for individuals at-risk.

Lastly, it would be interesting to examine the differences, if any, in the functioning of the reward system and potential interactions with other individual differences can be used to identify protective factors. Not all individuals at-risk for problem gambling develop an addiction severe enough to meet clinical criteria of pathological gambling. There is also a subset of individuals who do not view gambling as an enjoyable activity. Identifying factors that prevent someone from engaging in gambling in the first place or developing an addiction can further inform treatment options and government regulations. Compared to personality or cognitions, changes in the brain are more rapid and thus reflect the state of the system more accurately. Electrophysiological measures could provide the most up to date reflection of treatment progress and could potentially aid in timely identifications of individuals at-risk for relapsing.

The relationship between gambling experience and functioning of the reward system is a relatively new avenue for research. The methods available for such examination are constantly improving and becoming more widely available. There is still a large gap in the literature linking differences in personality and cognitions held by individuals with PG and responsivity of the reward system. Understanding of the interplay of these factors will provide us with a better understanding of development of

addictions as well as the role of the reward system in every day behaviour and individual differences.

Summary

The research conducted for this dissertation suggests that any influences of medial PFC on the activity of the ACC that occur in the context of incentive tasks are not direct. The FRN, which was defined to be a marker of ACC activity, was shown to be sensitive to salient stimulus characteristics and likely to reflect a general (not only reward-specific) prediction error signal. Dopamine is one of the neurotransmitters implicated in incentive learning and the FRN is thought to be a product of the dopaminergic signal from the subcortical areas to the ACC. Thus, it should not be surprising that the same signal can be used in coding information salient for learning. The results of this dissertation partially support the reinforcement learning theory, in that the FRN is a marker for dopaminergic signal of prediction error. However, the pattern of results outlined here suggests that prediction errors are based on salient stimulus characteristics and is not reward specific. Thus, the model of FRN generation should be updated such that prediction errors relayed to the ACC are based on a combination of salient stimulus characteristics valuable for learning and future behavioural adjustment. Further testing of this model in individuals at-risk for addictions can aid in identifying biological markers of at-risk factors and inform prevention and treatment options.

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Table 1.1
Average amount of money earned by participants in each condition of the task.

Task	Experiment 1	Experiment 2
Cue – No-Control	*M* = 6.43	*M* = 5.41
	SD = 1.68	*SD* = 1.72
Cue – Some-Control	*M* = 8.77	*M* = 7.89
	SD = 3.31	*SD* = 2.94
Cue – Full-Control	*M* = 8.73	*M* = 8.83
	SD = 0.56	*SD* = 1.19
No Cue – No-Control	*M* = 13.25	NA
	SD = 2.62	
No cue – Some-Control	*M* = 13.75	*M* = 13.5
	SD = 0.63	*SD* = 0.81
No Cue – Full-Control	*M* = 8.61	*M* = 8.13
	SD = 0.51	*SD* = 1.58

Table 1.2
Means and standard deviations of responses on the End of Task questionnaires, broken down by sense of control condition, for Experiments 1 (N = 12).

	Experiment 1		
Question	No-Control	Some-Control	Full-Control
Were you paying attention to the cues?	*M* = 2.50 *SD* = 1.24	*M* = 2.92 *SD* = 1.73	*M* = 3.00 *SD* = 1.60
Were the cues helpful (red/green vs mixed)?	*M* = 2.25 *SD* = 1.42	*M* = 2.67 *SD* = 1.50	*M* = 3.08 *SD* = 1.73
Did you have a feeling of control over the outcome?	*M* = 0.50 *SD* = 0.67	*M* = 1.58 *SD* = 1.31	*M* = 2.50 *SD* = 1.45
Could you predict the outcome?	*M* = 0.67 *SD* = 0.78	*M* = 1.18 *SD* = 1.08	*M* = 2.25 *SD* = 1.49
How accurate were you at predicting the outcome?	*M* = 0.67 *SD* = 0.78	*M* = 1.67 *SD* = 1.07	*M* = 2.18 *SD* = 1.25
How confident were you in your predictions?	*M* = 0.75 *SD* = 0.75	*M* = 1.67 *SD* = 1.16	*M* = 2.17 *SD* = 1.64
How often did you feel you would win?	*M* = 2.17 *SD* = 0.72	*M* = 2.25 *SD* = 0.97	*M* = 2.42 *SD* = 0.90
How often did you feel you would lose?	*M* = 2.25 *SD* = 0.62	*M* = 2.27 *SD* = 1.27	*M* = 2.73 *SD* =.65
Were you paying attention to the feedback?	*M* = 2.50 *SD* = 1.17	*M* = 3.25 *SD* = 1.55	*M* = 3.58 *SD* = 1.24
Was the feedback helpful?	*M* = 2.17 *SD* = 1.40	*M* = 3.25 *SD* = 1.42	*M* = 3.58 *SD* = 1.08
How tiered/bored are you?	*M* = 3.00 *SD* = 1.41	*M* = 2.33 *SD* = 1.72	*M* = 2.42 *SD* = 1.40

Table 1.3
Results of repeated measures ANOVA comparing the variability in reaction times across different levels of sense of control in Experiment 1 (N = 12).

Source	df_{effect}, df_{error}	*F*	*p*	$p\eta^2$
No-Control				
Cue	1, 11	2.51	.141	.186
Valence	3, 33	1.52	.242	.122
Cue x Valence	3, 33	2.25	.101	.169
Some-Control				
Cue	1, 11	0.27	.616	.024
Valence	3, 33	1.53	.225	.122
Cue x Valence	3, 33	0.72	.548	.061
Full-Control				
Cue	1, 11	1.98	.187	.153
Valence*	**3, 33**	**58.01**	**>.001**	**.841**
Cue x Valence	3, 33	2.35	.117	.176

Table 1.4
Means and standard deviations for the reaction times in each condition of the task, broken down by four types of outcomes, in Experiment 1.

Task Condition	Win	No Win	No Loss	Loss
Experiment 1				
No-Control - Cue	*M* = 235.70	*M* = 248.78	*M* = 234.68	*M* = 246.42
	SD = 45.21	*SD* = 42.24	*SD* = 39.59	*SD* = 42.11
No-Control – No Cue	*M* = 231.91	*M* = 230.32	*M* = 226.21	*M* = 222.99
	SD = 28.20	*SD* = 34.33	*SD* = 27.13	*SD* = 30.29
Some-Control - Cue	*M* = 240.74	*M* = 239.73	*M* = 252.25	*M* = 242.10
	SD = 34.26	*SD* = 42.17	*SD* = 45.34	*SD* = 45.17
Some-Control – No Cue	*M* = 244.43	*M* = 236.17	*M* = 244.76	*M* = 239.99
	SD = 41.34	*SD* = 36.12	*SD* = 34.84	*SD* = 35.12
Full-Control - Cue	*M* = 165.21	*M* = 249.52	*M* = 167.28	*M* = 242.08
	SD = 29.37	*SD* = 49.68	*SD* = 27.59	*SD* = 35.41
Full-Control – No Cue	*M* = 162.21	*M* = 267.57	*M* = 166.84	*M* = 254.03
	SD = 27.66	*SD* = 61.28	*SD* = 26.69	*SD* = 50.48

Table 1.5
Repeated measures ANOVA for the FRN amplitude elicited by the feedback across three midline channels (Fz, FC and Cz) in Experiment 1 (N = 12).

Source	df_{effect}, df_{error}	*F*	*p*	$p\eta^2$
Cue	1,11	0.31	.586	.028
Sense of Control (S of C)	2,22	0.97	.397	.081
Valence*	**1,11**	**5.62**	**.037**	**.338**
Channel	2,22	1.26	.290	.103
Cue x S of C	2,22	0.99	.387	.083
Cue x Valence	1,11	0.13	.722	.012
S of C x Valence	2,22	0.21	.730	.019
Cue x S of C x Valence	2,22	0.06	.940	.006
Cue x Channel	2,22	2.02	.179	.155
S of C x Channel	4,44	1.39	.266	.112
Cue x S of C x Channel	4,44	0.63	.528	.054
Valence x Channel	2,22	1.35	.275	.109
Cue x Valence x Channel	2,22	0.03	.941	.003
S of C x Valence x Cue	4,44	2.30	.131	.173
Cue x S of C x Valence x Channel	4,44	0.26	.739	.023

Table 1.6

Means and standard errors for the FRN amplitude following wins and losses across the six task conditions from Experiment 1 (N = 12).

Task Condition				
Loss	Fz	FCz	Cz	Marginal Mean
Cue – Full-Control	*M* = -2.25 *SD* = 2.63	*M* = -1.88 *SD* = 1.74	*M* = -1.63 *SD* = 1.85	*M* = -1.92 *SE* = .49
Cue – Some-Control	*M* = -2.37 *SD* = 2.06	*M* = -1.77 *SD* = 2.15	*M* = -1.67 *SD* = 1.71	*M* = -1.93 *SE* = 0.48
Cue – No-Control	*M* = -2.82 *SD* = 2.45	*M* = -2.16 *SD* = 2.43	*M* = -1.69 *SD* = 1.79	*M* = -2.22 *SE* = 0.62
No Cue – Full-Control	*M* = -1.88 *SD* = 1.32	*M* = -1.48 *SD* = 1.42	*M* = -1.44 *SD* = 1.72	*M* = -1.96 *SE* = 0.39
No Cue – Some-Control	*M* = -2.36 *SD* = 1.91	*M* = -1.77 *SD* = 1.73	*M* = -1.60 *SD* = 1.86	*M* = -1.91 *SE* = 0.48
No Cue – No-Control	*M* = -2.21 *SD* = 1.50	*M* = -2.18 *SD* = 1.51	*M* = -1.92 *SD* = 1.56	*M* = -2.10 *SE* = 0.41
Marginal Means	*M* = -2.31 *SE* = 0.48	*M* = -1.87 *SE* = .44	*M* = -1.66 *SE* = .42	*M* = -1.95 *SE* = 0.41
Win	Fz	FCz	Cz	Marginal Mean
Cue – Full-Control	*M* = -2.08 *SD* = 2.47	*M* = -1.51 *SD* = 2.14	*M* = -1.53 *SD* = 2.05	*M* = -1.70 *SE* = 0.54
Cue – Some-Control	*M* = -1.58 *SD* = 1.76	*M* = -0.98 *SD* = 1.36	*M* = -1.63 *SD* = 1.43	*M* = -1.39 *SE* = 0.36
Cue – No-Control	*M* = -2.32 *SD* = 1.58	*M* = -2.00 *SD* = 1.18	*M* = -1.23 *SD* = 1.25	*M* = -1.85 *SE* = 0.34
No Cue – Full-Control	*M* = -1.78 *SD* = 2.29	*M* = -1.29 *SD* = 1.48	*M* = -1.24 *SD* = 1.62	*M* = -1.44 *SE* = 0.43
No Cue – Some-Control	*M* = -1.51 *SD* = 1.90	*M* = -1.46 *SD* = 1.59	*M* = -1.95 *SD* = 1.64	*M* = -1.64 *SE* = 0.34
No Cue – No-Control	*M* = -1.95 *SD* = 2.03	*M* = -1.85 *SD* = 2.00	*M* = -1.53 *SD* = 1.33	*M* = -1.78 *SE* = 0.47
Marginal means	*M* = -1.87 *SE* =.49	*M* = -1.51 *SE* = .38	*M* = -1.52 *SE* = .33	*M* = -1.63 *SE* = 0.35

Table 1.7
Results of repeated measures ANOVA comparing the FRN amplitude in No Cue/Some-Control and Cue/Full-Control conditions in Experiment 1 (N = 12).

Source	df_{effect}, df_{error}	F	p	$p\eta^2$
Task	1,11	0.02	.895	.002
Valence	1,11	1.57	.237	.125
Channel	2,22	0.42	.661	.037
Task x Valence	1,11	0.01	.936	.001
Task x Channel	2,22	0.45	.558	.039
Valence x Channel	2,22	2.41	.141	.180
Task x Valence x Channel	2,22	2.18	.156	.165

Table 1.8
Means and standard deviations of responses on the End of Task questionnaires, broken down by sense of control condition, for Experiments 2 (N =12).

	Experiment 2		
Question	No-Control	Some-Control	Full-Control
Were you paying attention to the cues?	*M* = 2.63 *SD* = 1.73	*M* = 3.50 *SD* = 1.31	*M* = 3.67 *SD* = 0.99
Were the cues helpful (red/green vs mixed)?	*M* = 1.42 *SD* = 1.58	*M* = 2.17 *SD* = 1.12	*M* = 2.83 *SD* = 1.64
Did you have a feeling of control over the outcome?	*M* = 0.50 *SD* = 1.29	*M* = 2.18 *SD* = 1.40	*M* = 3.42 *SD* = 1.56
Could you predict the outcome?	*M* = 0.25 *SD* = 0.62	*M* = 2.00 *SD* = 1.54	*M* = 2.50 *SD* = 1.83
How accurate were you at predicting the outcome?	*M* = 1.50 *SD* = 1.19	*M* = 2.00 *SD* = 1.41	*M* = 2.42 *SD* = 1.68
How confident were you in your predictions?	*M* = 0.92 *SD* = 1.20	*M* = 2.25 *SD* = 1.29	*M* = 2.75 *SD* = 1.29
How often did you feel you would win?	*M* = 1.86 *SD* = 1.85	*M* = 2.50 *SD* = 1.00	*M* = 3.33 *SD* = 0.99
How often did you feel you would lose?	*M* = 2.38 *SD* = 0.98	*M* = 2.67 *SD* = 1.07	*M* = 2.75 *SD* = 0.97
Were you paying attention to the feedback?	*M* = 1.29 *SD* = 1.25	*M* = 3.50 *SD* = 1.38	*M* = 3.92 *SD* = 0.90
Was the feedback helpful?	*M* = 1.42 *SD* = 1.65	*M* = 2.92 *SD* = 1.73	*M* = 3.75 *SD* = 1.22
How tiered/bored are you?	*M* = 3.12 *SD* = 1.32	*M* = 2.58 *SD* = 1.44	*M* = 2.33 *SD* = 1.44

Table 1.9
*Results of repeated measures ANOVA comparing the variability in **reaction times** across different outcomes (i.e., loss/no loss/win/no win) and levels of sense of control in Experiment 2 (N = 12).*

Source	df_{effect}, df_{error}	*F*	*p*	$p\eta^2$
No-Control				
Valence*	**3,33**	**6.12**	**.002**	**.358**
Some-Control				
Cue	1, 11	0.29	.602	.025
Valence	3, 33	2.13	.115	.162
Cue x Valence	3, 33	2.73	.060	.119
Full-Control				
Cue	1, 11	0.11	.748	.010
Valence	3, 33	3.11	.099	.220
Cue x Valence	3, 33	0.63	.599	.054

Table 1.10
*Means and standard deviations for the **reaction times** in each condition of the task, broken down by four types of outcomes, in Experiment 2 (N = 12).*

Task Condition	Win	No Win	No Loss	Loss
No-Control - Cue	*M* = 276.44 *SD* = 54.30	*M* = 272.30 *SD* = 57.59	*M* = 285.63 *SD* = 60.23	*M* = 294.43 *SD* = 62.69
Some-Control - Cue	*M* =263.29 *SD* = 36.50	*M* = 280.61 *SD* = 41.52	*M* = 266.92 *SD* = 26.52	*M* = 277.49 *SD* = 31.95
Some-Control – No Cue	*M* = 272.45 *SD* = 36.85	*M* = 274.61 *SD* = 39.27	*M* = 285.21 *SD* = 42.16	*M* = 270.10 *SD* = 47.02
Full-Control - Cue	*M* = 164.45 *SD* = 36.04	*M* = 191.41 *SD* = 64.55	*M* = 160.70 *SD* = 42.08	*M* = 190.09 *SD* = 65.52
Full-Control – No Cue	*M* = 160.43 *SD* = 42.60	*M* = 187.91 *SD* = 65.56	*M* = 164.53 *SD* = 36.83	*M* = 181.93 *SD* = 72.60

Table 1.11
*Repeated measures ANOVA for the **FRN amplitude** elicited by the feedback across three midline channels (Fz, FC and Cz) for Experiment 2 (N = 12).*

Source	df_{effect}, df_{error}	F	p	$p\eta^2$
Cue	1,11	1.96	.189	.151
Sense of Control (S of C)	1,11	2.50	.142	.185
Valence *	**1,11**	**8.29**	**.015**	**.430**
Channel	2,22	3.22	.086	.226
Cue x S of C*	**1,11**	**6.54**	**.027**	**.373**
Cue x Valence	1,11	0.01	.912	.001
S of C x Valence	1,11	0.42	.530	.037
Cue x S of C x Valence	1,11	1.10	.316	.091
Cue x Channel	2,22	2.03	.178	.156
S of C x Channel	2,22	0.09	.828	.008
Cue x S of C x Channel	2,22	0.28	.668	.025
Valence x Channel	2,22	2.15	.165	.163
Cue x Valence x Channel	2,22	1.33	.285	.108
S of C x Valence x Cue*	**2,22**	**9.08**	**.001**	**.452**
Cue x S of C x Valence x Channel	2,22	2.11	.165	.161

Table 1.12
*Repeated measures ANOVA for the **FRN amplitude** elicited by the feedback in the **Cue conditions** across three midline sites for Experiment 2 (N = 12).*

Source	df_{effect}, df_{error}	F	p	$p\eta^2$
Sense of Control (S of C)*	**2,22**	**3.71**	**.041**	**.252**
Valence*	**1,11**	**6.34**	**.029**	**.366**
Channel	2,22	0.90	.222	.424
S of C x Valence!	2,22	0.11	.898	.010
S of C x Channel	4,44	1.71	.206	.135
Valence x Channel	2,22	1.31	.285	.107
S of C x Valence x Channel	4,44	1.57	.220	.125

Table 1.13
*Repeated measures ANOVA for the **FRN amplitude** following feedback in the **No Cue conditions** across the midline sites for Experiment 2 (N = 12).*

Source	df_{effect}, df_{error}	F	p	$p\eta^2$
Sense of Control (S of C)	1,11	0.25	.628	.248
Valence*	**1,11**	**4.90**	**.049**	**.308**
Channel	2,22	1.06	.336	.088
S of C x Valence	1,11	1.27	.283	.104
S of C x Channel	2,22	0.04	.890	.003
Valence x Channel	2,22	1.07	.341	.089
S of C x Valence x Channel*	**2,22**	**8.40**	**.005**	**.433**

Table 1.14
*Repeated measures ANOVA for the **FRN amplitude** elicited by the feedback in the **No Cue conditions** conducted at each midline channel, in Experiment 2 (N = 12).*

Source	df_{effect}, df_{error}	*F*	*p*	$p\eta^2$
Fz				
Sense of Control (S of C)	1, 11	0.20	.663	.151
Valence *	**1, 11**	**6.14**	**.031**	**.358**
S of C x Valence *	**1, 11**	**5.74**	**.035**	**.343**
FCz				
Sense of Control (S of C)	1, 11	1.34	.272	.108
Valence	1, 11	0.09	.765	.008
S of C x Valence	1, 11	1.96	.189	.151
Cz				
Sense of Control (S of C)	1, 11	0.20	.661	.018
Valence	1, 11	3.53	.087	.243
S of C x Valence	1, 11	1.91	.194	.148

Table 1.15
*Repeated measures ANOVA for the **FRN amplitude**, elicited by the feedback, conducted across midline channels for **each level of sense of control conditions** in Experiment 2 (N = 12).*

Source	df_{effect}, df_{error}	*F*	*p*	$p\eta^2$
Non-informative cue				
No-Control	NA			
Some-Control				
Valence *	**1, 11**	**7.50**	**.019**	**.405**
Channel	2, 22	1.22	.302	.099
Valence x Channel *	**2, 22**	**5.52**	**.028**	**.334**
Full-Control				
Valence	1, 11	0.58	.461	.050
Channel	2, 22	0.48	.537	.042
Valence x Channel	2, 22	2.84	.097	.205
Informative cue				
No-Control				
Valence	1, 11	2.79	.123	.202
Channel *	**2, 22**	**0.04**	**.884**	**.003**
Valence x Channel	2, 22	0.64	.492	.055
Some-Control				
Valence	1, 11	2.63	.134	.192
Channel *	**2, 22**	**7.68**	**.011**	**.411**
Valence x Channel	2, 22	2.46	.119	.183
Full-Control				
Valence	**1, 11**	**4.66**	**.054**	**.298**
Channel	2, 22	3.10	.077	.220
Valence x Channel	2, 22	1.20	.308	.098

Table 1.17
*Results of the repeated measures 2 (cue) x 2 (sense of control) x 4 (channel) ANOVA on the **difference wave** amplitude at the **central channel locations** (Experiment 2).*

Source	df_{effect}, df_{error}	*F*	*p*	$p\eta^2$
Cue	1, 11	0.92	.358	.077
Sense of Control (SofC)	1, 11	0.93	.355	.078
Channel	7, 77	1.61	.231	.128
Cue x SofC	1, 11	0.02	.904	.001
Cue x Channel	7, 77	0.60	.588	.051
SofC x Channel *	**7, 77**	**4.09**	**.045**	**.271**
Cue x SofC x Channel	7, 77	2.70	.089	.197

Table 1.18
Repeated measures ANOVA conducted on the average amplitude measures of the ***difference waves*** *following the onset of feedback in the* ***Some and Full-Control conditions*** *(Experiment 2; N = 12).*

Source	df_{effect}, df_{error}	*F*	*p*	$p\eta^2$
Some-Control				
Cue	1, 11	0.34	.574	.030
Channel *	**7, 77**	**6.92**	**.011**	**.386**
Cue x Channel	7, 77	1.73	.184	.136
Full-Control				
Cue	1, 11	0.81	.387	.069
Channel	7, 77	0.22	.708	.020
Cue x Channel	7, 77	1.41	.265	.114

Table 1.19
Repeated measures ANOVA conducted on the average amplitude measures of the ***difference waves*** *following the onset of the outcome in the* ***No Cue and Cue condition*** *of the Experiment 2 (N = 12).*

Source	df_{effect}, df_{error}	*F*	*p*	$p\eta^2$
No Cue				
Sense of Control (S of C)	1,11	2.08	.177	.159
Channel	7,77	0.85	.420	.072
S of C x Channel*	**7,77**	**5.16**	**.024**	**.319**
Cue				
Sense of Control (S of C)	2,22	1.11	.347	.092
Channel	7,77	0.71	.513	.061
S of C x Channel	14,154	1.20	.326	.098

Table 1.20
Repeated measures ANOVA conducted on the average amplitude measures of the ***difference waves*** *following the onset of the outcome in the* ***No Cue condition at the central/posterior and frontal sites*** *(Experiment 2; N = 12).*

Source	df_{effect}, df_{error}	F	p	$p\eta^2$
Central/Posterior				
Sense of Control (S of C)	1,11	3.09	.107	.219
Channel	3,33	2.13	.159	.162
S of C x Channel	3,33	1.29	.295	.105
Frontal				
Sense of Control (S of C) *	**1,11**	**7.34**	**.020**	**.400**
Channel	3,33	1.19	.322	.098
S of C x Channel	3,33	0.76	.460	.064

Table 1.21
Summary of the effects found at the time of the FRN (200 – 320 ms) after conducting a robust 2(cue) x 2 (valence) ANOVA conducted for each subject.

	Time period of significant effects		
Participant ID	Main effect of Cue	Main effect of Valence	Cue by Valence Interaction
T14	246 - 269	205 - 223; 249 - 266	none
T15	207- 216; 246 - 267; 294 - 317	209 - 218	none
T16	before 200	None	none
T17	278 - 284	269 - 275	none
T18	227 - 248; 286 - 308	202 - 213; 247 - 258	none
T19	279 - 287	216 – 227	none
T20	217 - 236; 269 - 287	197 - 207; 238 - 278	none
T21	286 - 315	283 - 360	none
T22	265 - 277	None	none
T23	225 - 247	240 - 259; 277 - 288	none
T24	None	214 - 222	none
T25	None	209 - 221	none

Table 2.1
Demographic information split by gambling behaviour and risk group.

	Non-gamblers (*N*=10)	Recreational gamblers (*N*=12)	Low risk PG (*N*=5)	Moderate risk PG (*N*=6)	High risk PG (*N*=8)
Age	*M* = 27.40 *SD* = 9.90 Range: 19-50	*M* = 34.17 *SD* =10.88 Range: 20-50	*M* = 30.80 *SD* =10.94 Range: 19-44	*M* = 29.17 *SD* =5.49 Range: 22-37	*M* =30.25 *SD* =8.83 Range: 20-44
Sex	*Mode: N* = 9 Male (90.0%)	*Mode: N* = 8 Female (66.7%)	*Mode: N* = 4 Males (80.0%)	*Mode: N* = 4 Males (33.3%)	*Mode: N* = 7 Males (87.5%)
Handedness	*Mode: N* = 9 Right (90.0%)	*Mode: N* = 8 Right (66.7%)	*Mode: N* = 5 Right (100%)	*Mode: N* = 6 Right (100.0%)	*Mode: N* = 6 Right (75.0%)
Highest level of education	*Mode: N* = 9 Some college/university (90.0%)	*Mode: N* = 4 High school/equivalent (33.3%)	*Mode: N* = 3 Some college or university (60.0%)	*Mode: N* = 4 Some college or university (66.7%)	*Mode: N* = 4 High school/equivalent (50.0%)
Ethic background	*Mode: N* = 8 White/Caucasian (80.0%)	*Mode: N* = 7 White/Caucasian (58.3%)	*Mode: N* = 5 White/Caucasian (100.0%)	*Mode: N* = 6 White/Caucasian (100.0%)	*Mode: N* = 7 White/Caucasian (87.5%)
Smoking frequency	*N* = 15 Non-smoker (50.0%)	*Mode: N* = 10 Non-smoker (83.3%)	*Mode: N* = 3 Smoker (60.0%) (*n* = 3 cigarettes a day)	*Mode: N* = 4 Non-smoker (66.7%)	*N* = 4 Non-smoker (50.0%) *Range: 2-10 cigarettes a day

Table 2.1 (cont'd)

	Non-gamblers (*N*=7)	Recreational gamblers (*N*=12)	Low risk PG (*N*=5)	Moderate risk PG (*N*=6)	High risk PG (*N*=8)
Drinking frequency	*Mode: N* = 2 ~6 drinks a week (range: .10 – 6) *Do not drink: *N* = 4 (40.0%)	*Mode: N* = 7 Do drink (58.3%), but for 2 data is missing (range: 0-24 drinks a week)	*Mode: N* = 4 Do drink (80.0%), but for 1 data is missing (range: 0.5-24)	*Mode: N* = 3 ~4 drinks a week (50.0%.3%; range: 1-60) *Do not drink: *N* = 0	*Range:* ~1-30 drinks a week (no mode) *Do not drink *N* = 3 (37.5%)
Gambling frequency***	NA	*M* = 5.67 *SD* =6.30	*M* = 15.50 *SD* =11.21	*M* = 24.33 *SD* = 20.34	*M* = 21.88 *SD* =9.03
# of Gambling activities	NA	*M* = 3.83 *SD* =3.10 *Mode: N* = 4, 4 activities (33.3%)	*M* = 7.00 *SD* =4.64 *Mode: N* = 2, 7 activities (40.0%)	*M* = 9.50 *SD* = 3.51 Range from 5 to 14 activities (no mode)	*M* = 9.50 *SD* =2.07 *Mode: N* = 2, 9 and 10 activities (25.0% each)
PGSI Score	NA	NA	*M* =1.2 *SD* = 0.44 *Mode: N* = 4, Score of 1 (80.0%)	*M* = 4.67 *SD* =1.21 *Mode: N* = 2, Score of 4 and 6 (33.3% each)	*M* = 10.0 *SD* = 2.14 *Mode: N* = 3, Score of 8 (37.5% each)

*No significant age effects (F(4,36)=0.72, p=.584

**Significant difference in distribution of:

- males across groups (χ^2=10.64, *p*=.031) (7 cells less than 5 expected)
- handedness across groups (χ^2=7.07, *p*=.529) (12 less than 5 expected)
- education level (χ^2=26.86, *p*=.043) (24 less than 5 expected)
- ethnic background (χ^2=9.62, *p*=.886) (22 less than 5 expected)
- smoking behaviour (χ^2=4.44, *p*=.350) (8 cells less than 5 expected)
- alcohol consumption (χ^2=4.09, *p*=.394) (7 cells less than 5 expected)

***Higher numbers, means more often, but can be the same game

****Significant difference between the groups (i.e., gamblers only) on gambling frequency (*F*(3,26)=4.89, *p*=.008) or number of gambling activities engaged in the past year (*F*(3,26)=6.60, *p*=.002). Such that at risk for PG differed from no risk, but no differences between gamblers.

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Table 2.2
Descriptive Information and Results of Statistical Analysis for the End of Task Questionnaire following the Doors Task comparing 'no risk for PG' and 'at risk for PG' groups.

Question	No Risk for PG (N = 22)	At Risk for PG (N = 19)	Results of Statistical Analysis Conducted
How often did you win on a 1-cue trial?	M = 2.95 SD = 1.43	M = 3.73 SD =1.33	U = 194.5, p = .682
How often did you win on a 2-cue trial?	M = 2.48 SD = 0.91	M = 2.84 SD = 0.60	U = 156.0, p = .137
How often did you win on a 3-cue trial?	M = 3.41 SD = 1.22	M = 3.95 SD = 0.97	U = 159.5, p = .179
Did you feel you could predict the outcome?*	M = 1.91 SD = 1.31	M = 2.44 SD = 1.30	U = 160.5, p = .289
How confident were you in your predictions?	M = 2.33 SD = 1.24	M = 2.95 SD = 1.03	U = 151.0, p = .171
How accurate were you at predicting the outcome?*	M = 2.41 SD = 1.14	M = 2.89 SD = 0.83	U = 154.5, p = .207
Did you have a strategy?	Yes: N = 0	Yes: N =0	NA

*Several individuals in the 'at risk for PG' group failed to respond to these questions (one participant per question), thus N = 18.

Table 2.3
Descriptive Information and Results of Statistical Analysis for the End of Task Questionnaire following the Time Estimation Task comparing 'no risk for PG' and 'at risk for PG' groups.

Question	No Risk for PG (N = 22)	At Risk for PG (N = 19)	Results of Statistical Analysis Conducted
Were the cues helpful?	M = 2.95 SD =1.43	M = 3.74 SD = 1.33	p = .064
Did you have a feeling of control over the outcome?	M = 2.82 SD = 1.40	M = 3.32 SD = 1.70	p = .120
How often did you feel you would win on an easy cue?	M = 3.05 SD = 1.05	M = 3.36 SD = 1.01	p = .330
How often did you feel you would lose on a hard trial?	M = 3.00 SD = 0.82	M = 2.95 SD = 0.97	p = .989
How confident were you in your predictions?	M = 3.33 SD = 0.91	M = 3.05 SD = 1.65	p = .767
How accurate were you at predicting the outcomes?	M = 2.86 SD = 0.83	M = 2.74 SD = 1.05	p = .856
How hard did you try on an easy cue?*	M = 3.90 SD = 1.02	M = 3.83 SD = 1.15	p = .898
How hard did you try on a hard cue?*	M = 4.36 SD = 0.58	M = 4.63 SD = 0.76	p = .056
Was the feedback helpful?	M = 3.68 SD = 1.13	M = 3.78 SD = 0.65	p = .864
Did you have a strategy?	Yes: N = 18	Yes: N = 19	p =.489

*Compare how hard did they try on a easy/hard cue: Z = -3.70, p < .001

Table 2.4
Results of a mixed ANOVA Examining the Effects of Cue Type and Group Membership (nPG and PG) on the Number of Times Participants Predicted a Win in the Doors task.

Trial Type	No Risk for PG (N =22)	At Risk for PG (N = 19)	Overall (N = 41)
Cue 1	M = 38.45	M = 39.89	M = 39.19
	SD = 35.63	SD = 27.64	SD = 31.79
Cue 2	M = 73.86	M = 78.32	M = 75.93
	SD = 30.68	SD = 23.87	SD = 27.49
Cue 3	M = 104.63	M = 99.63	M = 102.31
	SD = 11.78	SD = 16.76	SD = 14.34

Table 2.5
Descriptive Information and Results of Independent t-test Comparing Reaction Times for the 'no risk for PG' and 'at risk for PG' groups.

Condition	No Risk for PG (N = 22)	At Risk for PG (N = 19)	Results of Statistical Analysis Conducted
Doors Task (F (1,20) = 1.91, p = .165, $p\eta^2$ = .046)			
Cue '1' Trial	M = 1479.61 SD = 786.57	M = 1239.85 SD = 722.58	t (39) = 1.01, p = .319
Cue '2' Trial	M = 1422.23 SD = 757.96	M = 1189.51 SD = 718.25	t (39) = 1.00, p = .321
Cue '3' Trial	M = 1425.83 SD = 740.34	M = 1153.72 SD = 614.77	t (39) = 1.27, p = .212
Average RT (all trials)	M = 1442.56 SD = 748.78	M = 1194.36 SD = 673.46	t (39) = 1.11, p = .274
Time Estimation Task			
'Easy' Trial*	M = 829.08 SD = 385.36	M = 628.97 SD = 313.33	t (39) = 1.81, p = .079
'Hard' Trial*	***M* = 832.38** ***SD* = 395.97**	***M* = 602.55** ***SD* = 316.03**	***t* (39) = 2.03, *p* = .049**
Loss on Easy Trial	M = 850.20 SD = 400.01	M = 656.62 SD = 351.43	t (39) = 1.63, p = .111
Win on Easy Trial	M = 851.81 SD = 406.08	M = 660.45 SD = 332.63	t (39) = 1.63, p = .110
Loss on Hard Trial	M = 837.45 SD = 389.56	M = 641.29 SD = 342.82	t (39) = 1.70, p = .097
Win on Hard Trial	M = 853.62 SD = 424.25	M = 644.14 SD = 383.32	t (39) = 1.65, p = .107
Average RT (all trials)	M = 830.73 SD = 390.09	M = 615.76 SD = 310.30	t (39) = 1.93, p = .061

* Easy versus Hard cue comparison: t(40) = 0.85, p = .399

Table 2.6
Mixed repeated measures ANOVA for the FRN amplitude elicited by the feedback at across the three midline channels.

Source	df_{effect}, df_{error}	*F*	*p*	$p\eta^2$
Task (T)	1, 39	1.22	.277	.030
Task x Gambling group (PG Gr)	1, 39	1.99	.166	.049
Expectations (E)	**1, 39**	**13.28**	**.001**	**.254**
Expectations x PG Gr	1,39	> 0.01	.994	> .001
Valence (V)	**1,39**	**14.92**	**> .001**	**.277**
Valence x PG Gr	1,39	0.62	.437	.016
Channel (C)	**2,78**	**4.64**	**.017**	**.106**
Channel x PG Gr	2,78	1.43	.246	.035
Task x Expectations	**1,39**	**7.26**	**.010**	**.157**
Task x Expectation x PG Gr	**1,39**	**4.56**	**.039**	**.105**
Task x Valence	**1,39**	**11.36**	**.002**	**.229**
Task x Valence x PG Gr	1,39	1.02	.320	.025
Expectations x Valence	1,39	0.42	.521	.011
Expectations x Valence x PG Gr	1,39	0.19	.607	.005
T x E x V	1,39	0.22	.640	.006
T x E x V x PG Gr	1,39	2.77	.104	.066
Task x Channel	2,78	0.67	.474	.017
Task x Channel x PG Gr	2,78	0.70	.463	.018
Expectations x Channel	**2,78**	**3.95**	**.029**	**.092**
Expectations x Channel x PG Gr	2,78	0.18	.811	.004
T x E x C	2,78	0.89	.397	.022
T x E x C x PG Gr	2,78	0.14	.822	.004
Valence x Channel	**2,78**	**29.95**	**> .001**	**.434**
Valence x Channel x PG Gr	*2,78*	*3.43*	*.057*	*.081*
T x V x C	*2,78*	*3.49*	*.051*	*.082*
T x V x C x PG Gr	2,78	0.23	.725	.006
E x V x C	2,78	0.48	.574	.012
E x V x C x PG Gr	2,78	1.00	.358	.025
T x E x V x C	2,78	0.11	.817	.003
T x E x V x C x PG Gr	2,78	0.68	.456	.017
Between subjects effects				
Gambling group	1,39	1.48	.231	.037

Table 2.7
*Repeated measures ANOVAs for wins and losses examining the **FRN amplitude** at midline channels elicited in both tasks in individuals **not at risk** for Problem Gambling.*

Source	df_{effect}, df_{error}	*F*	*p*	$p\eta^2$
Loss				
Task (T)	**1, 21**	**16.82**	**.001**	**.445**
Expectations (E)	**1, 21**	**4.55**	**.045**	**.178**
Channel (C)	2, 42	3.52	.059	.144
Task x Expectations	1, 21	1.17	.293	.053
Task x Channel	2, 42	0.64	.496	.030
Expectations x Channel	2, 42	3.60	.058	.146
T x E x C	2, 42	0.53	.547	.025
Win				
Task (T)	1, 21	0.91	.352	.041
Expectations (E)	1, 21	1.77	.198	.078
Channel (C)	2, 42	2.84	.085	.119
Task x Expectations	1, 21	3.33	.082	.137
Task x Channel	2, 42	0.31	.701	.014
Expectations x Channel	2, 42	0.21	.733	.010
T x E x C	2, 42	0.41	.622	.019

Table 2.8
*Repeated measures ANOVAs for wins and losses examining the **FRN amplitude** at midline channels elicited in both tasks in individuals **at risk** for Problem Gambling.*

Source	df_{effect}, df_{error}	*F*	*p*	$p\eta^2$
Loss				
Task (T)	1, 18	0.78	.389	.042
Expectations (E)	1, 18	1.88	.188	.094
Channel (C)	2, 36	1.11	.335	.058
Task x Expectations *	**1, 18**	**8.15**	**.011**	**.312**
Task x Channel	2, 36	0.02	.955	.001
Expectations x Channel	2, 36	0.96	.377	.051
T x E x C	2, 36	0.34	.618	.019
Win				
Task (T)	**1, 18**	**4.81**	**.042**	**.211**
Expectations (E)	**1, 18**	**7.75**	**.012**	**.301**
Channel (C)	**2, 36**	**7.60**	**.002**	**.297**
Task x Expectations	**1, 18**	**4.50**	**.048**	**.200**
Task x Channel	**2, 36**	**4.89**	**.021**	**.212**
Expectations x Channel	2, 36	0.53	.577	.029
T x E x C	**2, 36**	**4.34**	**.021**	**.194**

Table 2.9
*Repeated measures ANOVA for the **FRN amplitude** elicited by the feedback at midline channels in individuals **not at risk** for Problem Gambling.*

Source	df_{effect}, df_{error}	F	p	$p\eta^2$
Doors				
Expectations (E)	**1,21**	**6.56**	**.018**	**.238**
Valence (V)	1,21	0.94	.762	.040
Channel (C)	2,42	1.34	.269	.060
Expectations x Valence	1,21	0.41	.528	.019
Expectations x Channel	2,42	1.53	.233	.068
Valence x Channel	2,42	2.40	.130	.102
E x V x C	2,42	0.54	.565	.025
Time Estimation Task				
Expectations (E)	1,21	2.31	.144	.099
Valence (V)	**1,21**	**14.76**	**.001**	**.413**
Channel (C)	2,42	2.11	.153	.091
Expectations x Valence	1,21	2.72	.114	.115
Expectations x Channel	2,42	1.01	.359	.046
Valence x Channel	**2,42**	**7.03**	**.004**	**.251**
E x V x C	2,42	1.01	.356	.046

Table 2.10

Repeated measures ANOVA for the FRN peak amplitude elicited by the feedback in Doors task in individuals at risk for Problem Gambling.

Source	df_{effect}, df_{error}	*F*	*p*	$p\eta^2$
Doors				
Expectations (E)	**1,18**	**14.91**	**.001**	**.453**
Valence (V)	1,18	2.58	.126	.125
Channel (C)	2,36	1.66	.212	.084
Expectations x Valence	1,18	0.90	.356	.047
Expectations x Channel	2,36	1.75	.164	.088
Valence x Channel	**236**	**8.46**	**.004**	**.320**
E x V x C	2,36	0.35	.617	.019
Time Estimation				
Expectations (E)	1,18	0.24	.631	.013
Valence (V)	**1,18**	**8.70**	**.009**	**.326**
Channel (C)	**2,36**	**3.84**	**.033**	**.176**
Expectations x Valence	1,18	0.11	.750	.006
Expectations x Channel	2,36	0.49	.586	.027
Valence x Channel	**236**	**15.86**	**> .001**	**.468**
E x V x C	2,36	0.36	.617	.020

Table 2.11

*Results of the mixed ANOVA for the **FRN amplitude** elicited by the feedback across three midline channels in **non-gamblers and high-risk gamblers**.*

Source	df_{effect}, df_{error}	*F*	*p*	$p\eta^2$
Task (T)	1,16	1.33	.265	.077
Task x Gambling group (PG Gr)	1,16	3.54	.078	.181
Expectations (E)*	**1,16**	**4.97**	**.040**	**.237**
Expectations x PG Gr	1,16	0.47	.501	.029
Valence (V)*	**1,16**	**21.03**	**<.001**	**.568**
Valence x PG Gr	1,16	0.08	.774	.005
Channel (C)*	1,16	2.46	.136	.133
Channel x PG Gr	1,16	4.27	.055	.211
Task x Expectations*	1,16	2.10	.166	.116
Task x Expectation x PG Gr	1,16	2.52	.132	.136
Task x Valence*	**1,16**	**26.60**	**<.001**	**.624**
Task x Valence x PG Gr	1,16	1.08	.314	.063
Expectations x Valence	1,16	0.04	.844	.002
Expectations x Valence x PG Gr	1,16	0.56	.467	.034
T x E x V	1,16	2.10	.166	.116
T x E x V x PG Gr	1,16	0.21	.656	.013
Task x Channel	1,16	0.00	.977	.000
Task x Channel x PG Gr	1,16	0.13	.727	.008
Expectations x Channel*	**1,16**	**19.32**	**<.001**	**.547**
Expectations x Channel x PG Gr	1,16	0.67	.426	.040
T x E x C	1,16	2.86	.110	.152
T x E x C x PG Gr	1,16	0.75	.398	.045
Valence x Channel	1,16	3.69	.073	.187
Valence x Channel x PG Gr	1,16	0.02	.897	.001
T x V x C	1,16	0.54	.473	.033
T x V x C x PG Gr	1,16	0.51	.486	.031
E x V x C	1,16	0.49	.494	.030
E x V x C x PG Gr	1,16	0.23	.642	.014
T x E x V x C	1,16	0.63	.440	.038
T x E x V x C x PG Gr	1,16	0.16	.690	.010
Gambling group	1,16	0.25	.624	.015

Table 2.12
*Results of the mixed ANOVA for the **FRN latency** elicited by the feedback across three midline channels.*

Source	df_{effect}, df_{error}	F	p	$p\eta^2$
Task (T)	1,39	3.55	.067	.084
Task x Gambling group (PG Gr)	1,39	0.01	.929	.000
Expectations (E)*	**1,39**	**4.89**	**.033**	**.111**
Expectations x PG Gr	1,39	0.54	.465	.014
Valence (V)*	**1,39**	**8.39**	**.006**	**.177**
Valence x PG Gr	1,39	< 0.01	> .999	<.001
Channel (C)*	**2,78**	**36.86**	**.000**	**.486**
Channel x PG Gr	2,78	1.07	.322	.027
Task x Expectations	1,39	0.42	.519	.011
Task x Expectation x PG Gr	1,39	0.84	.364	.021
Task x Valence	1,39	1.09	.303	.027
Task x Valence x PG Gr	1,39	0.89	.350	.022
Expectations x Valence	1,39	2.32	.136	.056
Expectations x Valence x PG Gr	1,39	0.71	.403	.018
T x E x V	1,39	0.07	.793	.002
T x E x V x PG Gr	1,39	0.05	.818	.001
Task x Channel	2,78	1.89	.170	.046
Task x Channel x PG Gr	2,78	2.96	.074	.071
Expectations x Channel	2,78	0.52	.543	.013
Expectations x Channel x PG Gr	2,78	0.41	.604	.010
T x E x C	2,78	0.50	.569	.013
T x E x C x PG Gr	2,78	0.90	.394	.022
Valence x Channel	2,78	2.53	.106	.061
Valence x Channel x PG Gr	2,78	0.27	.683	.007
T x V x C	2,78	1.33	.268	.033
T x V x C x PG Gr	2,78	0.02	.956	.001
E x V x C	2,78	2.07	.141	.051
E x V x C x PG Gr	2,78	2.05	.144	.050
T x E x V x C	2,78	0.38	.683	.010
T x E x V x C x PG Gr	2,78	1.85	.165	.045
Between subjects				
Gambling group	1,39	2.81	.102	.067

Table 2.13
*Results of the mixed ANOVA for the **average difference wave amplitude** at the time of the FRN across the midline channels.*

Source	df_{effect}, df_{error}	F	p	$p\eta^2$
Task (T)*	**1,39**	**33.18**	**< .001**	**.460**
Task x Gambling group (PG Gr)	1,39	0.68	.414	.017
Expectations (E)*	**1,39**	**5.94**	**.020**	**.132**
Expectations x PG Gr	1,39	0.45	.507	.011
Channel (C)	3,177	3.20	.057	.076
Channel x PG Gr	3,177	0.37	.650	.009
Task x Expectations	1,39	3.07	.088	.073
Task x Expectation x PG Gr	1,39	2.00	.166	.049
Task x Channel*	**3,177**	**13.67**	**< .001**	**.259**
Task x Channel x PG Gr	3,177	0.25	.761	.006
Expectations x Channel	3,177	2.00	.155	.049
Expectations x Channel x PG Gr	3,177	0.15	.798	.004
T x E x C	3,177	2.45	.102	.059
T x E x C x PG Gr	3,177	0.51	.572	.013
Between subjects				
Gambling group	1,39	1.99	.167	.048

Table 2.14

*Results of the repeated measures ANOVA for the **average difference wave amplitude** at the time of the FRN across the midline channels for **each group**.*

Source	df_{effect}, df_{error}	*F*	*p*	$p\eta^2$
Not at risk for problem gambling				
Task (T)*	**1,21**	**7.78**	**.018**	**.414**
Expectations (E)	1,21	2.36	.153	.177
Channel (C)	3,33	0.68	.466	.059
Task x Expectations	1,21	4.32	.062	.282
Task x Channel*	**3,33**	**12.10**	**< .001**	**.524**
Expectations x Channel	3,33	0.64	.471	.055
T x E x C	3,33	1.19	.318	.098
At risk for problem gambling				
Task (T)*	**1,18**	**11.49**	**.003**	**.390**
Expectations (E)	1,18	3.87	.065	.177
Channel (C)	3,54	1.51	.238	.077
Task x Expectations	1,18	0.10	.761	.005
Task x Channel*	**3,54**	**4.57**	**.026**	**.203**
Expectations x Channel	3,54	1.64	.215	.083
T x E x C	3,54	0.76	.460	.040

Table 2.15
Means, Standard Deviations and Results of the Independent t-tests for the Locus of Control and HEXACO measures comparing 'no risk for PG' and 'at risk for PG' groups.

Individual Difference Measure	No Risk for PG	At Risk for PG	t-test Results
Locus of Control	*N* =21 *M* = 8.67 *SD* = 5.24	*N* = 16 *M* = 7.25 *SD* = 6.13	*t* (35) = 0.76, *p* = .454
Honesty-Humility	*N* = 21 *M* = 31.28 *SD* = 6.60	*N* = 19 *M* = 28.63 *SD* = 5.09	*t* (38) = 1.41, *p* = .166
Emotionality	***N* = 21** ***M* = 28.76** ***SD* = 6.43**	***N* = 18** ***M* = 33.39** ***SD* = 5.89**	***t* (37) = -2.33, *p* = .025**
Extraversion	*N* = 21 *M* = 34.05 *SD* =7.96	*N* = 19 *M* = 33.32 *SD* = 4.40	*t* (38) = 0.36, *p* = .725
Agreeableness	*N* = 21 *M* = 33.00 *SD* = 5.36	*N* = 18 *M* = 29.56 *SD* = 6.75	*t* (37) = 1.76, *p* = .084
Conscientiousness	***N* = 22** ***M* = 36.82** ***SD* = 6.32**	***N* = 18** ***M* = 31.39** ***SD* = 5.26**	***t* (38) = 2.91, *p* = .006**
Openness to Experience	*N* = 21 *M* = 38.81 *SD* = 6.93	*N* = 17 *M* = 36.06 *SD* = 6.86	*t* (36) = 1.22, *p* = .229

*Note: The degrees of freedom are different for each test as some participants had not responded to all of the questions on the questionnaires, resulting in a missing score on one of the subscales but not on others.

Table 2.16
Correlations between FRN peak amplitude, total PGSI score, Conscientiousness and Emotionality.

FRN measure	PGSI Total (N = 41)	Conscientiousness (N = 40)	Emotionality (N = 39)
Doors			
Expected Loss	-0.14	-0.08	-0.25
Expected Win	-0.07	0.04	-0.13
Unexpected Loss	-0.19	-0.08	-0.02
Unexpected Win	-0.12	-0.01	-0.05
Time Estimation			
Expected Loss	-0.07	0.16	-0.24
Expected Win	0.05	-0.15	-0.11
Unexpected Loss	0.11	-0.12	0.10
Unexpected Win	0.17	-0.14	-0.01

Table 2.17
Correlations between personality and residual scores of the FRN peak amplitude.

	Total PGSI Score (N=31)	Conscientiousness (N=30)	Emotionality (N=30)	Number of Gambling Activities (N=31)	Gambling Frequency (N=30)
Valence effects (DV: Loss)					
Doors: Unexpected	-0.17	-0.07	0.04	**-0.47****	-0.32
Doors: Expected	-0.13	-0.17	-0.16	-0.23	0.01
Time Estimation: Unexpected	< 0.01	0.05	0.07	-0.06	-0.05
Time Estimation: Expected	-0.18	0.32	-0.15	-0.22	-0.10
Expectation effects (DV: Unexpected)					
Doors: Loss	-0.11	-0.04	0.20	**-0.45***	-0.35
Doors: Win	-0.10	0.02	0.02	0.06	0.14
Time Estimation: Loss	0.18	-0.14	0.21	0.13	0.04
Time Estimation: Win	0.22	0.01	0.09	0.17	0.07
Sense of control effects: (DV: Time Estimation)					
Loss: Unexpected	0.13	0.05	0.07	0.17	0.10
Loss: Expected	-0.07	0.29	-0.01	-0.16	-0.11
Win: Unexpected	0.22	-0.13	0.07	0.03	-0.02
Win: Expected	0.05	-0.22	0.05	-0.12	-0.02

**p* < .05
***p* < .01

Table 2.18
Correlations between Gambling Frequency, Number of Gambling Activities Participated in, Locus of Control and HEXACO Subscales.

	Gambling Frequency	Number of Gambling Activities Engaged In
Locus of Control (*N* = 26, *N* = 27)	-0.06	-0.07
Openness to Experience (*N* = 27; *N* = 28)	-0.13	-0.07
Conscientiousness (*N* = 29; *N* = 30)	**-0.47***	-0.29
Extraversion (*N* = 29; *N* = 30)	0.15	0.07
Agreeableness (*N* = 28; *N* = 29)	**-0.45***	**-0.42***
Emotionality (*N* = 29; *N* = 30)	-0.18	-0.12
Honesty-Humility (*N* = 29; *N* = 30)	**-0.37***	-0.16

* $p < .05$

Table 2.19
Results of the Multiple Regression Analysis using Conscientiousness and Agreeableness to predict Gambling Frequency (*N* = 26).

	B	*SE B*	*β*	sr^2
Conscientiousness	-0.42	0.50	-0.16	0.02
Agreeableness	-0.82	0.39	-0.41	**0.15**
Honesty-Humility	-0.14	0.47	-0.06	< 0.01

*R^2 = .256, F (3,22) = 2.52, p = .084

Table 2.20
*Results of the Multiple Regression Analysis using **FRN peak amplitude** at Fz to predict **Gambling Frequency and Number of Gambling Activities** engaged in the past year.*

	B	*SE B*	*β*	sr^2	*p*
Gambling Frequency					
Doors Task					
Expected Loss	3.06	2.59	0.29	0.05	.248
Expected Win	-2.99	2.85	-0.26	0.04	.303
Unexpected Loss	-4.26	2.17	-0.43	0.13	.061
Unexpected Win	1.48	2.40	0.14	0.01	.542
Time Estimation Task					
Expected Loss	-1.80	2.75	-0.19	0.02	.518
Expected Win	-0.88	2.60	-0.10	< 0.01	.737
Unexpected Loss	0.67	2.57	0.07	< 0.01	.797
Unexpected Win	1.66	2.30	0.15	0.01	.617
Number of Gambling Activities					
Doors Task					
Expected Loss	0.14	0.71	0.04	< 0.01	.851
Expected Win	0.39	0.77	0.12	0.01	.616
Unexpected Loss	**-1.55**	**0.61**	**-0.52**	**0.19**	**.018**
Unexpected Win	-0.03	0.67	-0.01	< 0.01	.964
Time Estimation Task					
Expected Loss	-1.15	0.73	-0.40	0.08	.126
Expected Win	-0.52	0.73	-0.19	0.02	.486
Unexpected Loss	0.56	0.71	0.19	0.02	.440
Unexpected Win	0.72	0.60	0.31	0.05	.244

Table 2.21
*Results of the Multiple Regression Analysis using **FRN peak latency** at Fz to predict **Number of Gambling Activities** engaged in the past year.*

	B	*SE B*	*β*	sr^2	*p*
Gambling Frequency					
Doors Task					
Expected Loss	-0.04	0.08	-0.14	0.01	.582
Expected Win	-0.06	0.12	-0.15	0.01	.624
Unexpected Loss	0.01	0.08	0.02	< 0.01	.953
Unexpected Win	-0.09	0.09	-0.25	0.03	.322
Time Estimation Task					
Expected Loss	-0.06	0.06	-0.21	0.03	.335
Expected Win	0.03	0.07	0.10	0.01	.656
Unexpected Loss	-0.02	0.08	-0.05	< 0.01	.824
Unexpected Win	-0.14	0.09	-0.40	0.08	.107
Number of Gambling Activities					
Doors Task					
Expected Loss	-0.01	0.02	-0.10	0.01	.682
Expected Win	-0.02	0.03	-0.14	0.01	.630
Unexpected Loss	0.02	0.02	0.17	0.01	.502
Unexpected Win	-0.04	0.03	-0.37	0.22	.125
Time Estimation Task					
Expected Loss	-0.01	0.02	-0.15	0.01	.521
Expected Win	0.02	0.02	0.18	0.02	.449
Unexpected Loss	< 0.01	0.02	0.05	< 0.01	.874
Unexpected Win	-0.04	0.03	-0.36	0.07	.174

Table 2.22
Correlations between measures of personality/gambling severity/behaviour and residual scores of the FRN peak latency.

	Total PGSI Score (N=31)	Conscientiousness (N=30)	Emotionality (N=30)	Number of Gambling Activities (N=31)	Gambling Frequency (N=30)
Valence effects (DV: Loss)					
Doors: Unexpected	0.13	0.20	0.30	0.04	-0.13
Doors: Expected	-0.18	0.14	0.11	0.05	-0.06
Time Estimation: Unexpected	0.05	-0.16	0.13	-0.03	-0.10
Time Estimation: Expected	-0.11	0.15	0.06	-0.20	-0.31
Expectation effects (DV: Unexpected)					
Doors: Loss	0.31	0.07	0.26	-0.03	-0.12
Doors: Win	0.07	-0.26	-0.05	-0.28	-0.16
Time Estimation: Loss	0.06	-0.17	0.05	-0.08	-0.14
Time Estimation: Win	-0.16	0.23	-0.13	-0.31	-0.40
Sense of control effects: (DV: Time Estimation)					
Loss: Unexpected	-0.02	-0.13	0.04	-0.16	-0.27
Loss: Expected	-0.03	0.19	0.02	-0.14	-0.34
Win: Unexpected	-0.17	0.23	-0.12	-0.26	-0.16
Win: Expected	0.30	-0.21	0.25	0.16	0.03

Table 2.23
Results of the Multiple Regression Analysis using ***average difference wave amplitude*** *at C14 and C13 to predict* ***Gambling Frequency*** *and* ***Number of Gambling Activities****.*

	B	*SE B*	*β*	sr^2	*p*
Gambling Frequency					
Doors Task					
C14: R^2 = 0.02, *F* (2,27) =0.32 , *p* = .730					
Expected	-2.70	3.63	-0.17	0.02	.463
Unexpected	1.60	2.48	0.15	0.02	.525
C13: R^2 = 0.04, *F* (2,27) = 0.56, *p* =.580					
Expected	-2.41	2.91	-0.18	0.02	.414
Unexpected	2.56	2.62	0.21	0.03	.337
Time Estimation Task					
C14: R^2 = 0.14, *F* (2,27) = 2.13, *p* =.138					
Expected	*4.04*	*1.99*	*0.37*	*0.13*	*.052*
Unexpected	-1.5	1.81	-0.15	0.02	.415
C13: R^2 = 0.08, *F* (2,27) = 1.17, *p* =.327					
Expected	3.21	2.10	0.29	0.08	.138
Unexpected	-0.49	1.83	-0.05	< 0.01	.793
Number of Gambling Activities					
Doors Task					
C14: R^2 = 0.07, *F* (2,28) = 0.97, *p* = .392					
Expected	0.49	1.05	0.10	< 0.01	.641
Unexpected	0.60	0.72	0.18	0.02	.409
C13: R^2 = 0.07, *F* (2,28) = 1.10, *p* = .347					
Expected	0.46	0.83	0.12	0.01	.580
Unexpected	0.68	0.76	0.19	0.03	.378
Time Estimation Task					
C14: R^2 = 0.13, *F* (2,28) = 2.00, *p* = .155					
Expected	*1.17*	*0.59*	*0.36*	*0.12*	*.057*
Unexpected	-0.35	0.54	-0.12	0.01	.520
C13: R^2 = 0.10, *F* (2,28) = 1.48, *p* =.244					
Expected	1.03	0.60	0.32	0.10	.096
Unexpected	-0.21	0.53	-0.07	0.01	.692

APPENIDX 1.1

Study 1 Research Ethics Board Clearance Certificate

Brock University
Research Ethics Office
Tel: 905-688-5550 ext. 3035
Email: reb@brocku.ca

Bioscience Research Ethics Board

Certificate of Ethics Clearance for Human Participant Research

DATE: 2/19/2014

PRINCIPAL INVESTIGATOR: SEGALOWITZ, Sid - Psychology

FILE: 07-217 - SEGALOWITZ

TYPE: Faculty Research STUDENT: Angela Dzyundzyak
SUPERVISOR: Segalowitz

TITLE: Neurophysiological Reflections of Reward and Regulatory Responses in Gambling Tasks with Young Adults

ETHICS CLEARANCE GRANTED

Type of Clearance: RENEWAL Expiry Date: 2/27/2015

The Brock University Bioscience Research Ethics Board has reviewed the above named research proposal and considers the procedures, as described by the applicant, to conform to the University's ethical standards and the Tri-Council Policy Statement. Clearance granted from **2/19/2014 to 2/27/2015**.

The Tri-Council Policy Statement requires that ongoing research be monitored by, at a minimum, an annual report. Should your project extend beyond the expiry date, you are required to submit a Renewal form before **2/27/2015**. Continued clearance is contingent on timely submission of reports.

To comply with the Tri-Council Policy Statement, you must also submit a final report upon completion of your project. All report forms can be found on the Research Ethics web page at http://www.brocku.ca/research/policies-and-forms/research-forms.

In addition, throughout your research, you must report promptly to the REB:

a) Changes increasing the risk to the participant(s) and/or affecting significantly the conduct of the study;
b) All adverse and/or unanticipated experiences or events that may have real or potential unfavourable implications for participants;
c) New information that may adversely affect the safety of the participants or the conduct of the study;
d) Any changes in your source of funding or new funding to a previously unfunded project.

We wish you success with your research.

Approved:

Brian Roy, Chair
Bioscience Research Ethics Board

Note: Brock University is accountable for the research carried out in its own jurisdiction or under its auspices and may refuse certain research even though the REB has found it ethically acceptable.

If research participants are in the care of a health facility, at a school, or other institution or community organization, it is the responsibility of the Principal Investigator to ensure that the ethical guidelines and clearance of those facilities or institutions are obtained and filed with the REB prior to the initiation of research at that site.

Study 2 Research Ethics Board Clearance Certificate

Brock University
Research Ethics Office
Tel: 905-688-5550 ext. 3035
Email: reb@brocku.ca

Social Science Research Ethics Board

Certificate of Ethics Clearance for Human Participant Research

DATE:	5/7/2012		
PRINCIPAL INVESTIGATOR:	SEGALOWITZ, Sidney - Psychology		
FILE:	11-224 - SEGALOWITZ		
TYPE:	Ph. D.	STUDENT:	Angela Dzyundzyak
		SUPERVISOR:	Sidney Segalowitz

TITLE: The Role of Reward Expectancy in Brain Electrical Responses to Winning

ETHICS CLEARANCE GRANTED

Type of Clearance: NEW Expiry Date: 5/31/2013

The Brock University Social Sciences Research Ethics Board has reviewed the above named research proposal and considers the procedures, as described by the applicant, to conform to the University's ethical standards and the Tri-Council Policy Statement. Clearance granted from 5/7/2012 to 5/31/2013.

The Tri-Council Policy Statement requires that ongoing research be monitored by, at a minimum, an annual report. Should your project extend beyond the expiry date, you are required to submit a Renewal form before 5/31/2013. Continued clearance is contingent on timely submission of reports.

To comply with the Tri-Council Policy Statement, you must also submit a final report upon completion of your project. All report forms can be found on the Research Ethics web page at http://www.brocku.ca/research/policies-and-forms/research-forms.

In addition, throughout your research, you must report promptly to the REB:

a) Changes increasing the risk to the participant(s) and/or affecting significantly the conduct of the study;
b) All adverse and/or unanticipated experiences or events that may have real or potential unfavourable implications for participants;
c) New information that may adversely affect the safety of the participants or the conduct of the study;
d) Any changes in your source of funding or new funding to a previously unfunded project.

We wish you success with your research.

Approved:

Jan Frijters, Chair
Social Sciences Research Ethics Board

Note: Brock University is accountable for the research carried out in its own jurisdiction or under its auspices and may refuse certain research even though the REB has found it ethically acceptable.

If research participants are in the care of a health facility, at a school, or other institution or community organization, it is the responsibility of the Principal Investigator to ensure that the ethical guidelines and clearance of those facilities or institutions are obtained and filed with the REB prior to the initiation of research at that site.

APPEDIX 1.2

Date:
Project Title: **Brainwave Responses to Winning Money**

Principal Investigator:
Angela Dzyundzyak, PhD Candidate
Department of Psychology
Brock University
905-688-5550 x3034, ad03cr@brocku.ca

S.J. Segalowitz, Professor
Department of Psychology
Brock University
(905) 688-5550 Ext. 3465,
ssegalowitz@brocku.ca

Faculty Supervisor:

INVITATION

You are invited to participate in a study that involves research. The purpose of this study is to measure brain activity while performing a computerized task with various levels of difficulty.

WHAT'S INVOLVED

As a participant, you will be asked to answer some questionnaires assessing activity preferences and experience in participating in gambling behaviours. Then a brainwave sensor net will be placed on your scalp. You will be asked to complete some tasks on the computer requiring you to respond with a button press. There are three versions of the task such that you are asked to (a) press a button to let computer choose a card for you, (b) pick one of the two cards, or (c) respond within allotted amount of time in order to win or avoid losing. Once you have responded you will be given feedback indicating whether you won (or avoided a loss), or whether you lost (or simply won nothing). Each task will be divided into 6 blocks, 5 minutes each. After each version of the task the running total will be recorded and at the end of the experiment you will draw a number of the task at random. The amount accumulated during that task will be given to you as a monetary reward. Once the computer tasks are finished, the sensors will be removed. Participation will take approximately 3 hours of your time.

POTENTIAL BENEFITS AND RISKS

Possible benefits of participation include the chance to see your brain activity on a computer screen, and ask questions of the researchers about EEG procedures and brain health. There are no known or anticipated risks associated with participation in this study.

CONFIDENTIALITY

All information you provide is considered confidential; your name will not be included or, in any other way, associated with the data collected in the study. Furthermore, because our interest is in the average responses of the entire group of participants, you will not be identified individually in any way in written reports of this research.

Data collected during this study will be kept for 5 years after final publication of results and stored in a limited access area of the Brock Neuropsychology laboratory. Only researchers associated with the Brock Neuropsychology laboratory will have access to the data.

VOLUNTARY PARTICIPATION

Participation in this study is voluntary. If you wish, you may decline to answer any questions or participate in any component of the study. Further, you may decide to withdraw from this study at any time and may do so without any penalty or loss of benefits to which you are entitled. Participation hours will be awarded to the nearest half hour. Monetary compensation will be based on the amount of money won at the end of the tasks.

PUBLICATION OF RESULTS
Results of this study may be published in professional journals and presented at conferences. Feedback about this study will be available through Angela Dzyundzyak (ad03cr@brocku.ca). As EEG data takes a long time to analyze, we do not anticipate full results of the study to be ready until September 2013.

CONTACT INFORMATION AND ETHICS CLEARANCE
If you have any questions about this study or require further information, please contact the Principal Investigator or the Faculty Supervisor using the contact information provided above. This study has been reviewed and received ethics clearance through the Research Ethics Board at Brock University (REB #07- 217). If you have any comments or concerns about your rights as a research participant, please contact the Research Ethics Office at (905) 688-5550 Ext. 3035, reb@brocku.ca.
Thank you for your assistance in this project.

CONSENT FORM
I agree to participate in the study described above. I have made this decision based on the information I have read in the Information-Consent Letter. I have had the opportunity to receive any additional details I wanted about the study and understand that I may ask questions in the future. I understand that I may withdraw this consent at any time.

I am participating in this experiment for ____ hours of research participation in a psychology course as well as monetary reward ($10 to $15).

_____	_____	_____
Signature of participant	Course for participation	Signature of experimenter

OR

I am participating in this experiment for a monetary reward ($10 to $15). This experiment will not count toward research participation hours in a psychology course.

_____	_____
Signature of participant	Signature of experimenter

Subject ID _____ Date: _____

1. How old are you?_____ What is your major/occupation?_____
2. Sex: M F What are your goals after the completion of your current degree? _____
3. Have you ever been diagnosed/experienced any neurological conditions (e.g. epilepsy, stroke, concussion etc)?

   _____

4. Do you smoke cigarettes? Y N

   If yes, approximately how many a day? _____

5. Have you experienced any recent stressor (e.g. death in the family, birth of a child, etc)?_____
6. For each of these activities, please decide which hand you normally use but checking the box. In each case, imagine that you are actually carrying out the activity before answering.

	1 Always Left	2 Usually Left	3 Either Hand	4 Usually Right	5 Always Right	6 Not Sure
1. Which hand do you use to write?	☐	☐	☐	☐	☐	☐
2. Which hand is used to throw a ball?	☐	☐	☐	☐	☐	☐
3. Which hand is used to draw?	☐	☐	☐	☐	☐	☐
4. Which hand is used to cut with a knife?	☐	☐	☐	☐	☐	☐
5. Which hand is used to hold a tennis racquet?	☐	☐	☐	☐	☐	☐
6. Hammer in a nail, which hand wields the hammer?	☐	☐	☐	☐	☐	☐
7. Which hand uses scissors?	☐	☐	☐	☐	☐	☐
8. Which hand strikes a match?	☐	☐	☐	☐	☐	☐
9. Thread a needle, which hand moves?	☐	☐	☐	☐	☐	☐
10. Which hand deals the cards?	☐	☐	☐	☐	☐	☐

Problem Gambling Severity Index

This self-assessment is based on the Canadian Problem Gambling Index. It will give you a good idea of whether you need to take corrective action.

Thinking about the last 12 months…

	Never	Sometimes	Most of the time	Almost always
1. Have you bet more than you could really afford to lose?	0	1	2	3
2. Still thinking about the last 12 months, have you needed to gamble with larger amounts of money to get the same feeling of excitement?	0	1	2	3
3. When you gambled, did you go back another day to try to win back the money you lost?	0	1	2	3
4. Have you borrowed money or sold anything to get money to gamble?	0	1	2	3
5. Have you felt that you might have a problem with gambling?	0	1	2	3
6. Has gambling caused you any health problems, including stress or anxiety?	0	1	2	3
7. Have people criticized your betting or told you that you had a gambling problem, regardless of whether or not you thought it was true?	0	1	2	3
8. Has your gambling caused any financial problems for you or your household?	0	1	2	3
9. Have you felt guilty about the way you gamble or what happens when you gamble?	0	1	2	3

Gambling Behaviour Questionnaire

Frequency of the behaviour

PART A	***Please use THIS definition of gambling when you answer the rest of the questions on this survey.***

Gambling is betting / risking money on anything that is valuable to you (e.g, a CD, your bicycle, your computer, etc.) on an activity with an uncertain outcome.

The activities listed below are different types of gambling activities. How many times in the PAST YEAR have you done the following:

	NEVER IN THE PAST YEAR	1-5 TIMES IN THE PAST YEAR	6-11 TIMES A YEAR	ABOUT ONCE A MONTH	2-3 TIMES A MONTH	ABOUT ONCE A WEEK	2-6 TIMES A WEEK	DAILY
Played the lottery (i.e., 649, Super 7 or Pick 3)								
Played instant-win or scratch tickets								
Bought raffle tickets or fundraising tickets								
Played break open or pull tab tickets								
Played Sports Select/Pro-line								
Played bingo								
Bet on TV show outcomes (i.e. Survivor, Big Brother, The Bachelor, etc.)								
Played cards, board games with family or friends for money								
Played games of skill such as pool, golf, or darts for money								
Played arcade or video games for money								
Bet/gambled on the internet (i.e., poker, fantasy drafts, Facebook sports pools, games, etc.)								
Flipped coins / played dice games for money								
Played slot machines / poker or gambling machines / VLTs								
Bet on sports teams (e.g., hockey pools, football pools, any sports pools, etc.)								
Bet on horse races								
Played card or dice games at a casino								
Bet on sports with a bookie								
Bet money or objects on another game/activity that is not listed above (please specify): _____								

End of task Questionnaire (NC/SC/FC)

Please answer the following questions regarding your experiences during the tasks using the scales provided.

1. **Were you paying attention to the cues?**										
Not at all										All the time
0	1	2	3	4	5	6	7	8	9	10
2. Were the cues helpful (red/green vs mixed)?										Much more helpful
Not at all										
0	1	2	3	4	5	6	7	8	9	10
3. How much did you feel that your responses controlled the outcome?/Did you have a feeling of control over the outcome?										
Not at all										Very much
0	1	2	3	4	5	6	7	8	9	10
4. Could you predict the outcome?										All the time
Not at all										
0	1	2	3	4	5	6	7	8	9	10
5. How often did you feel you would win?										
Not at all										Usually
0	1	2	3	4	5	6	7	8	9	10
6. How confident were you in your predictions?										Very confident
Not at all										
0	1	2	3	4	5	6	7	8	9	10
7. Were you paying attention to the feedback (e.g., win, loss)?										All the time
Not at all										
0	1	2	3	4	5	6	7	8	9	10
8. How often did you feel you would lose?										
Not at all										Usually
0	1	2	3	4	5	6	7	8	9	10
9. How accurate were you at predicting the outcome?										Very accurate
Not at all										
0	1	2	3	4	5	6	7	8	9	10
10. Was the feedback helpful?										Most of the time
Not at all										
0	1	2	3	4	5	6	7	8	9	10
11. How tired/sleepy/bored are you?										
Not at all										Very much
0	1	2	3	4	5	6	7	8	9	10

12. Did you develop **any strategy** in your responding? If yes, please explain below.

13. Do you have any **other comments** about the task that we did not address? If yes, please use the space below to expand

Feedback Form: Brainwave Responses to Winning Money

Dear Participant,

Thank you for taking part in this study. Without the help of volunteers these types of studies could not be done.

The tasks you've completed today are designed to elicit a specific brain wave response - a feedback related negativity (FRN), which is a negative deflection in the event-related potential waveforms occurring about 200ms after the presentation of feedback (i.e., win or loss). This negativity has been found to vary depending on the context of the task, individual differences (e.g., sensitivity to punishment) as well as gambling experience. More specifically, larger FRNs were found for losses compared to wins (e.g., Gehring & Willoughby, 2002; Yeung & Sanfey, 2004) and for unexpected compared to expected outcomes (e.g., Bellebaum & Daum, 2008). The FRN is thought to reflect either (a) violation of expectation (i.e., larger for unexpected) or (b) failure to meet task goals (i.e., losing). Additionally, individuals with problem gambling behaviours showed earlier FRNs compared to non-gamblers (Oberg, et al., 2011), suggesting that their brain reacts to feedback information in a different way; however, it is unclear why this difference occurs (e.g., due to perceiving task gals differently or having different expectations).

One of the factors that has been shown to contribute to the development of problem gambling behaviour is perceived sense of control over the outcome. More specifically the higher levels of illusion of control, where individuals incorrectly feel sense of control over the outcome, are associated with higher risk for problem gambling behaviour (Johansson, et al., 2009). Thus, the purpose of this experiment was to examine the effect of sense of control (i.e., having a computer choose a card - No-Control, picking the card - Some-Control or responding fast enough - control) and predictive information (i.e., the cues) on the FRN amplitude. The results of this experiment will let us identify the best task to use in a follow up study examining brain activation of individuals with problem gambling habits.

Due the nature of the FRN and its sensitivity to probability (i.e., FRN is larger for low probability and low-frequency outcomes), we had to ensure comparable number of wins and losses across the conditions. In order to do this the outcomes in the tasks were either predetermined (No-Control and Some-Control conditions) or had a fixed difficulty level (control condition). This design allowed us to examine effects of sense of control and minimized any effects outcome frequency would have on the FRN.

If you would like to learn more about the results of this study you could call Angela Dzyundzyak at the 905-688-5550, Ext. 3034, or email her at ad03cr@brocku.ca. It takes a lot of time to do the analyses though so the results are not likely to be ready before September 2013; however, if you are interested in the results feel free to leave your email and we will let you know when the results are available.

If you have any concerns or would like to find out more about gambling-related issues the Niagara Alcohol and Drug Assessment Services (NADAS) website is a good resource (http://www.nadas.on.ca/). Additionally, NADAS (24-hour on call service: 905-684-1859) as well as the Student Development Center at Brock University (ext. 3240 or 5484) offer counselling services for individuals with gambling problems. Thank you again for taking part. Your help was very much appreciated.

If you have any issues you would like to discuss regarding your involvement in the study, you could call the Brock Research Ethics Board through the Research Office at 905-688-5550, Ext. 3035.

APPEDIX 1.3

Study 1: Task instructions

(condition titles were not presented to the participants)

No Cue/No-Control condition

"A cue indicating the start of the trial will appear on the screen. The trials are either a potential WIN where the worst you can do is not win money, OR a potential LOSS trial where the best you can do is avoid losing money. The cue will not inform you of the type of trial.

After the cue, two cards will appear on the screen. Either card can lead to a good outcome (win/no loss) or a bad outcome (loss/no win). The computer will chose a card for you after you press 4.

You have to press 4 while the cards are still on the screen.

The computer will show you which card was chosen by highlighting it with a blue border. A red border around the cards indicates that you did not press any button.

Start with a 4 trial practice."

Cue/No-Control condition

"A cue indicating the start of the trial will appear on the screen. The trials are either a potential WIN where the worst you can do is not win money, OR a potential LOSS trial where the best you can do is avoid losing money.

A GREEN cue means it's a potential WIN trial and RED cues mean it's a potential LOSS trial.

After the cue, two cards will appear on the screen. Either card can lead to a good outcome (win/no loss) or a bad outcome (loss/no win). The computer will chose a card for you after you press 4.

You have to press 4 while the cards are still on the screen.

The computer will show you which card was chosen by highlighting it with a blue border. A red border around the cards indicates that you did not press any button.

Start with a 4 trial practice."

No Cue/Some-Control condition

"A cue indicating the start of the trial will appear on the screen. The trials are either a potential WIN where the worst you can do is not win money, OR a potential LOSS trial where the best you can do is avoid losing money. The cue will not inform you of the type of trial.

After the cue, two cards will appear on the screen. Either card can lead to a good outcome (win/no loss) or a bad outcome (loss/no win). Your job is to pick a card.

Press 1 to choose the card on the left.

Press 4 to choose a card on the right.

You have to make your decision while the cards are still on the screen.

The computer will show you which card was chosen by highlighting it with a blue border. A red border around the cards indicates that you did not press any button.

Start with a 4 trial practice."

Cue/Some-Control condition

"A cue indicating the start of the trial will appear on the screen. The trials are either a potential WIN where the worst you can do is not win money, OR a potential LOSS trial where the best you can do is avoid losing money.

A GREEN cue means it's a potential WIN trial and RED cues mean it's a potential LOSS trial.

After the cue, two cards will appear on the screen. Either card can lead to a good outcome (win/no loss) or a bad outcome (loss/no win). Your job is to pick a card.

Press 1 to choose the card on the left.

Press 4 to choose a card on the right.

You have to make your decision while the cards are still on the screen.

The computer will show you which card was chosen by highlighting it with a blue border. A red border around the cards indicates that you did not press any button.

Start with a 4 trial practice."

No Cue/Full-Control condition

"A cue indicating the start of the trial will appear on the screen. The trials are either a potential WIN where the worst you can do is not win money, OR a potential LOSS trial where the best you can do is avoid losing money. The cue will not inform you of the type of trial.

After the cue, two cards will appear on the screen. To win or to avoid losing press 4 WHILE THE TWO CARDS ARE STILL ON THE SCREEN.

The two cards will reappear with a blue border to indicate that your response has been acknowledged by the computer. A red border around the cards indicates that you did not press any button.

Start with a 4 trial practice."

Cue/Full-Control condition

"A cue indicating the start of the trial will appear on the screen. The trials are either a potential WIN where the worst you can do is not win money, OR a potential LOSS trial where the best you can do is avoid losing money.

A GREEN cue means it's a potential WIN trial and RED cues mean it's a potential LOSS trial.

After the cue, two cards will appear on the screen. To win or to avoid losing press 4 WHILE THE TWO CARDS ARE STILL ON THE SCREEN.

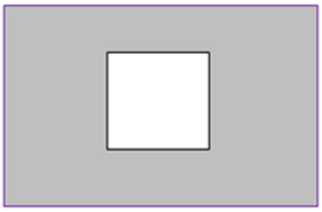
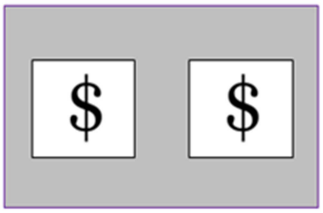
The two cards will reappear with a blue border to indicate that your response has been acknowledged by the computer. A red border around the cards indicates that you did not press any button.

Start with a 4 trial practice."

Study 1: Counterbalancing order

Order #	Experiment 1	Experiment 2
1	1. No-Control: (a) Cue (b) No Cue 2. Some-Control: (a) Cue (b) No Cue 3. Full-Control: (a) Cue (b) No Cue	1. No-Control 2. Some-Control: (a) Cue (b) No Cue 3. Full-Control: (a) Cue (b) No Cue
2	1. No-Control: (a) Cue (b) No Cue 2. Full-Control: (a) Cue (b) No Cue 3. Some-Control: (a) Cue (b) No Cue	1. No-Control 2. Full-Control: (a) Cue (b) No Cue 3. Some-Control: (a) Cue (b) No Cue
3	1. Some-Control: (a) Cue (b) No Cue 2. Full-Control: (a) Cue (b) No Cue 3. No-Control: (a) Cue (b) No Cue	1. Some-Control: (a) Cue (b) No Cue 2. Full-Control: (a) Cue (b) No Cue 3. No-Control
4	1. Some-Control: (a) Cue (b) No Cue 2. No-Control: (a) Cue (b) No Cue 3. Full-Control: (a) Cue (b) No Cue	1. Some-Control: (a) Cue (b) No Cue 2. No-Control 3. Full-Control: (a) Cue (b) No Cue
5	1. Full-Control: (a) Cue (b) No Cue 2. No-Control: (a) Cue (b) No Cue 3. Some-Control: (a) Cue (b) No Cue	1. Full-Control: (a) Cue (b) No Cue 2. No-Control 3. Some-Control: (a) Cue (b) No Cue
6	1. Full-Control: (a) Cue (b) No Cue 2. Some-Control: (a) Cue (b) No Cue 3. No-Control: (a) Cue (b) No Cue	1. Full-Control: (a) Cue (b) No Cue 2. Some-Control: (a) Cue (b) No Cue 3. No-Control
7	1. No-Control: (a) No Cue (b) Cue 2. Some-Control: (a) No Cue (b) Cue 3. Full-Control: (a) No Cue (b) Cue	1. No-Control 2. Some-Control: (a) No Cue (b) Cue 3. Full-Control: (a) No Cue (b) Cue
8	1. No-Control: (a) No Cue (b) Cue 2. Full-Control: (a) No Cue (b) Cue 3. Some-Control: (a) No Cue (b) Cue	1. No-Control 2. Full-Control: (a) No Cue (b) Cue 3. Some-Control: (a) No Cue (b) Cue
9	1. Some-Control: (a) No Cue (b) Cue 2. Full-Control: (a) No Cue (b) Cue 3. No-Control: (a) No Cue (b) Cue	1. Some-Control: (a) No Cue (b) Cue 2. Full-Control: (a) No Cue (b) Cue 3. No-Control
10	1. Some-Control: (a) No Cue (b) Cue 2. No-Control: (a) No Cue (b) Cue 3. Full-Control: (a) No Cue (b) Cue	1. Some-Control: (a) No Cue (b) Cue 2. No-Control 3. Full-Control: (a) No Cue (b) Cue
11	1. Full-Control: (a) No Cue (b) Cue 2. No-Control: (a) No Cue (b) Cue 3. Some-Control: (a) No Cue (b) Cue	1. Full-Control: (a) No Cue (b) Cue 2. No-Control 3. Some-Control: (a) No Cue (b) Cue
12	1. Full-Control: (a) No Cue (b) Cue 2. Some-Control: (a) No Cue (b) Cue 3. No-Control: (a) No Cue (b) Cue	1. Full-Control: (a) No Cue (b) Cue 2. Some-Control: (a) No Cue (b) Cue 3. No-Control

Study 1: Visual Angles

	Vertical	Horizontal	Presentation on the screen
Cue	5.06	5.06	
Target	5.06	11.89	
Feedback			
Win	1.05	3.25	
Loss	1.05	4.20	
No Win	1.05	6.49	
No Loss	1.05	7.44	

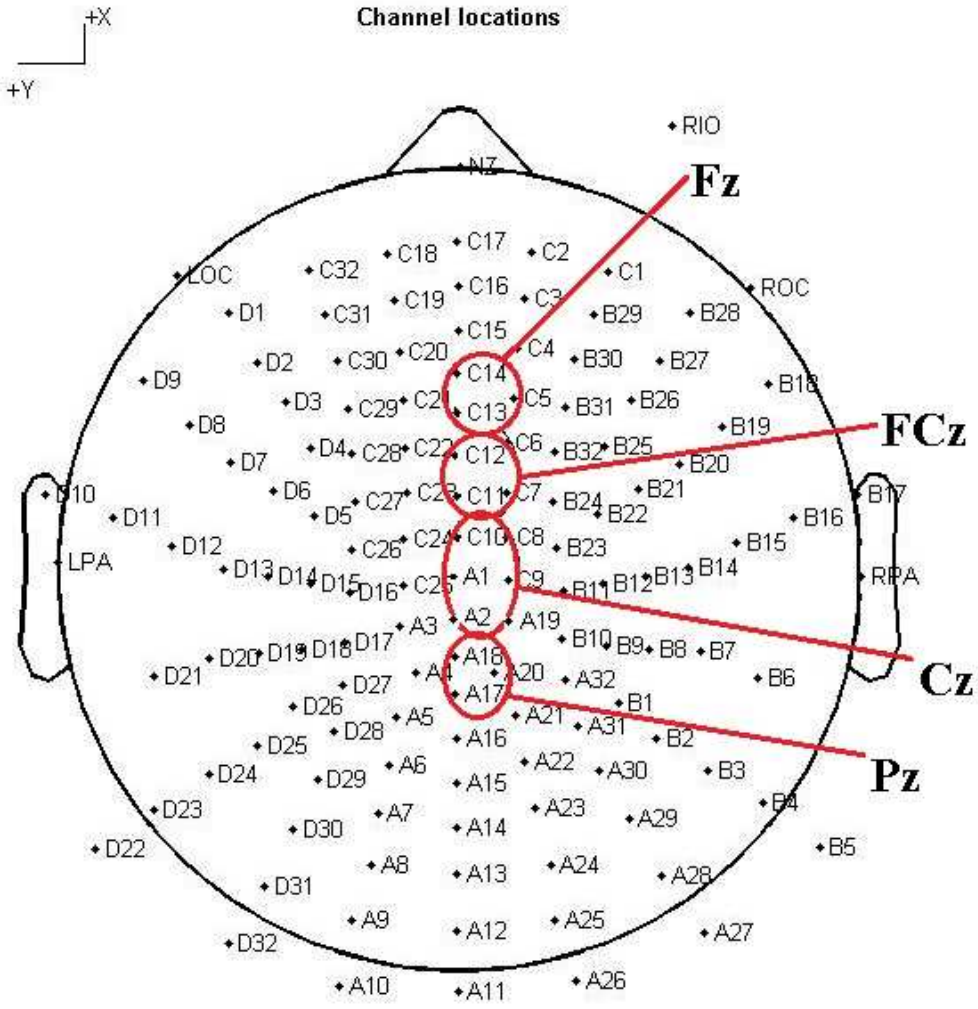
Study 1: Average number of trials used for FRN analysis in each condition (after artifact rejection).

Wave 1	**Cue**		**No Cue**	
	Win (Win/No Loss)	Loss (Loss/No Win)	Win (Win/No Loss)	Loss (Loss/No Win)
No-Control	70	52	70	51
range:	57-78	46-57	33-80	32-56
Some-Control	59	62	60	61
range:	48-68	54-70	50-69	55-71
Full-Control	81	47	80	46
range:	73-89	35-54	73-89	33-52

Wave 2	**Cue**		**No Cue**	
	Win (Win/No Loss)	Loss (Loss/No Win)	Win (Win/No Loss)	Loss (Loss/No Win)
No-Control	72	51	--	--
range:	52-83	36-57	--	--
Some-Control	60	62	61	63
range:	48-78	53-69	55-70	52-73
Full-Control	81	52	82	53
range:	70-91	46-60	73-91	47-58

APPENDIX 1.4

128 channel Biosemi Montage



APPENDIX 1.5

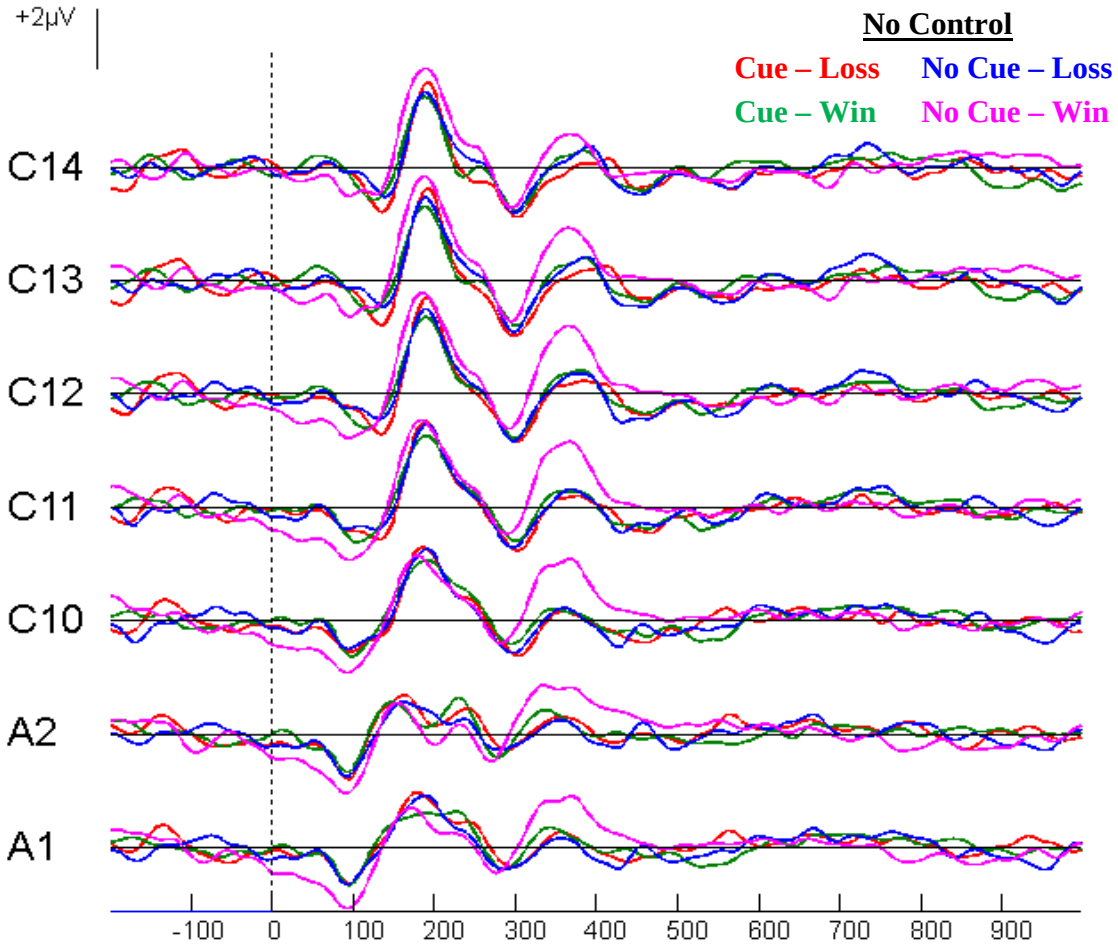


Figure 2.X. Averaged ERP waveforms for the two types of cues and two types of outcomes received in the No Control versions of the task Experiment 1.

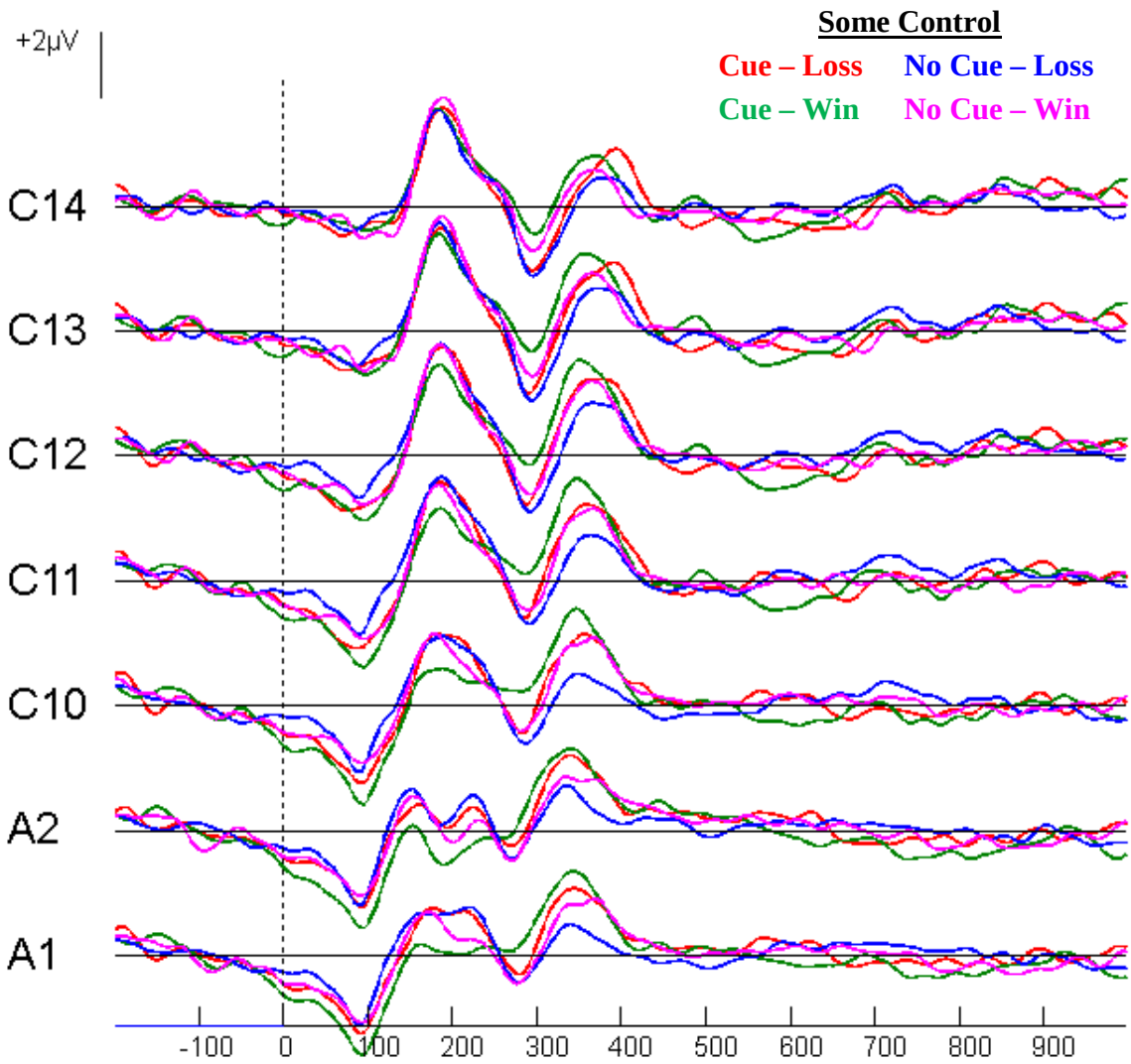


Figure 2.7. Averaged ERP waveforms for the two types of cues and two types of outcomes received in the Some Control versions of the task Experiment 1.

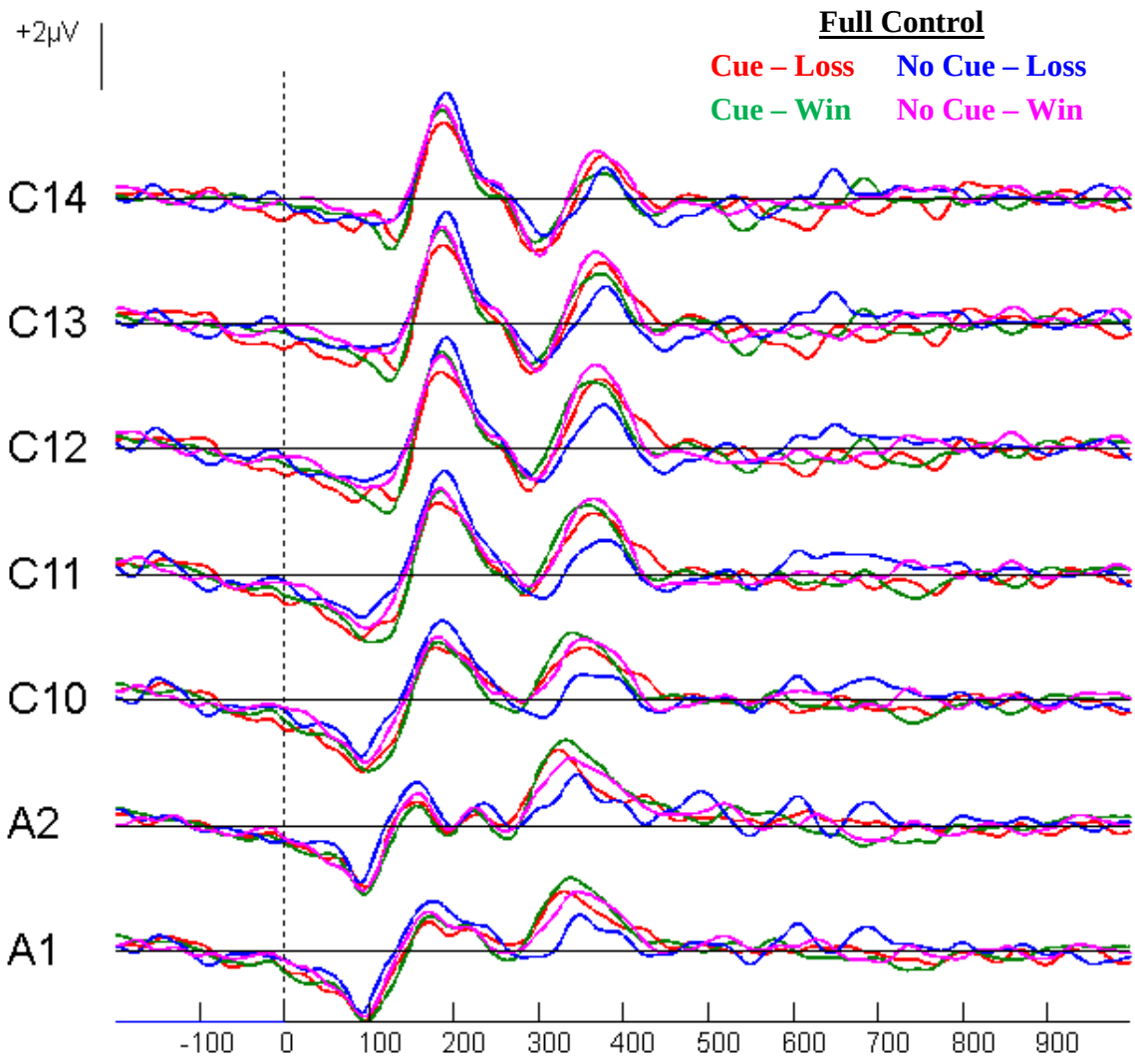


Figure 2.8. Averaged ERP waveforms for the two types of cues and two types of outcomes received in the Full Control versions of the task in Experiment 1.

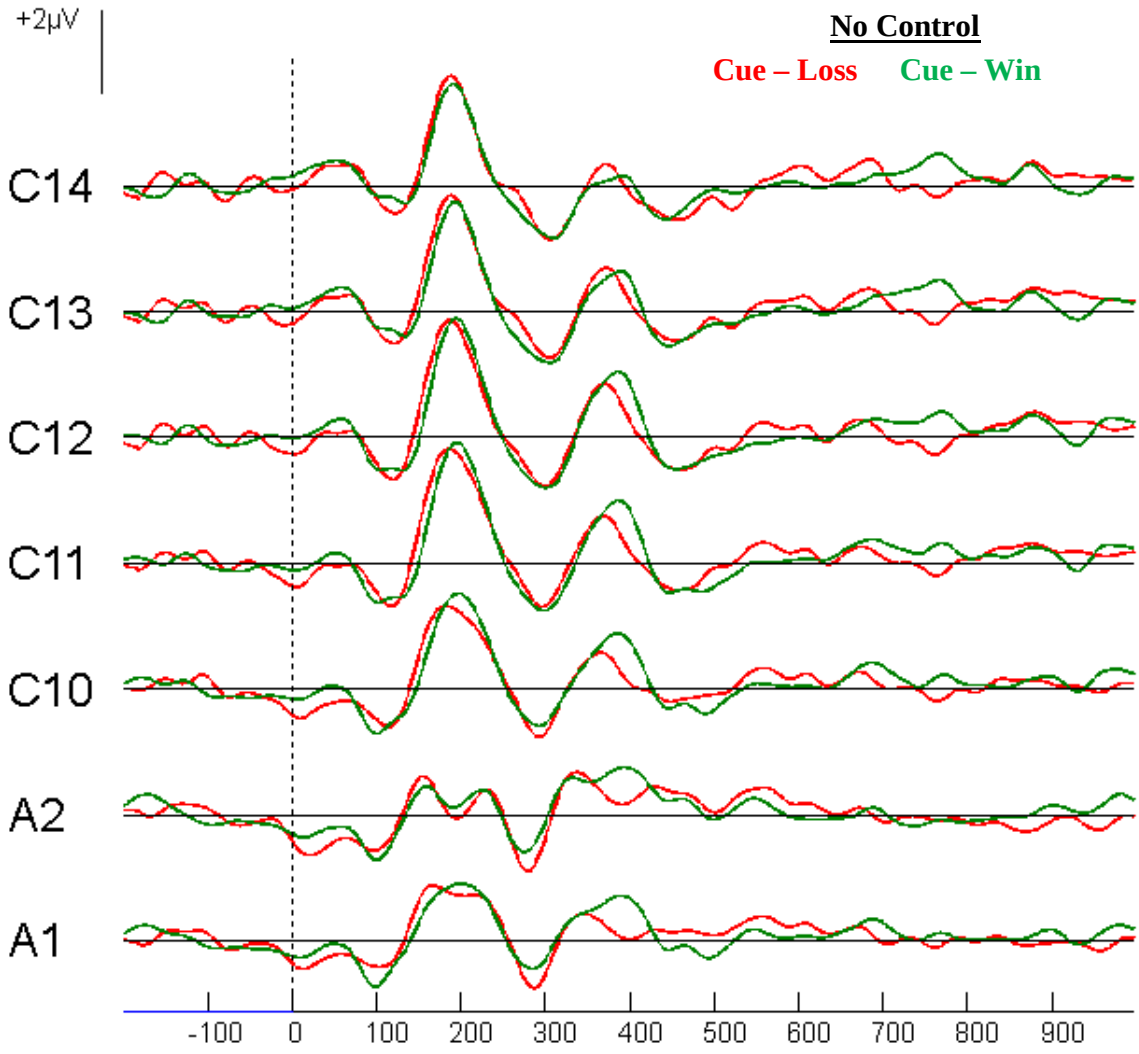


Figure 2.10. Averaged ERP waveforms for the two types of cues and two types of outcomes received in the No Control versions of the task observed in Experiment 2

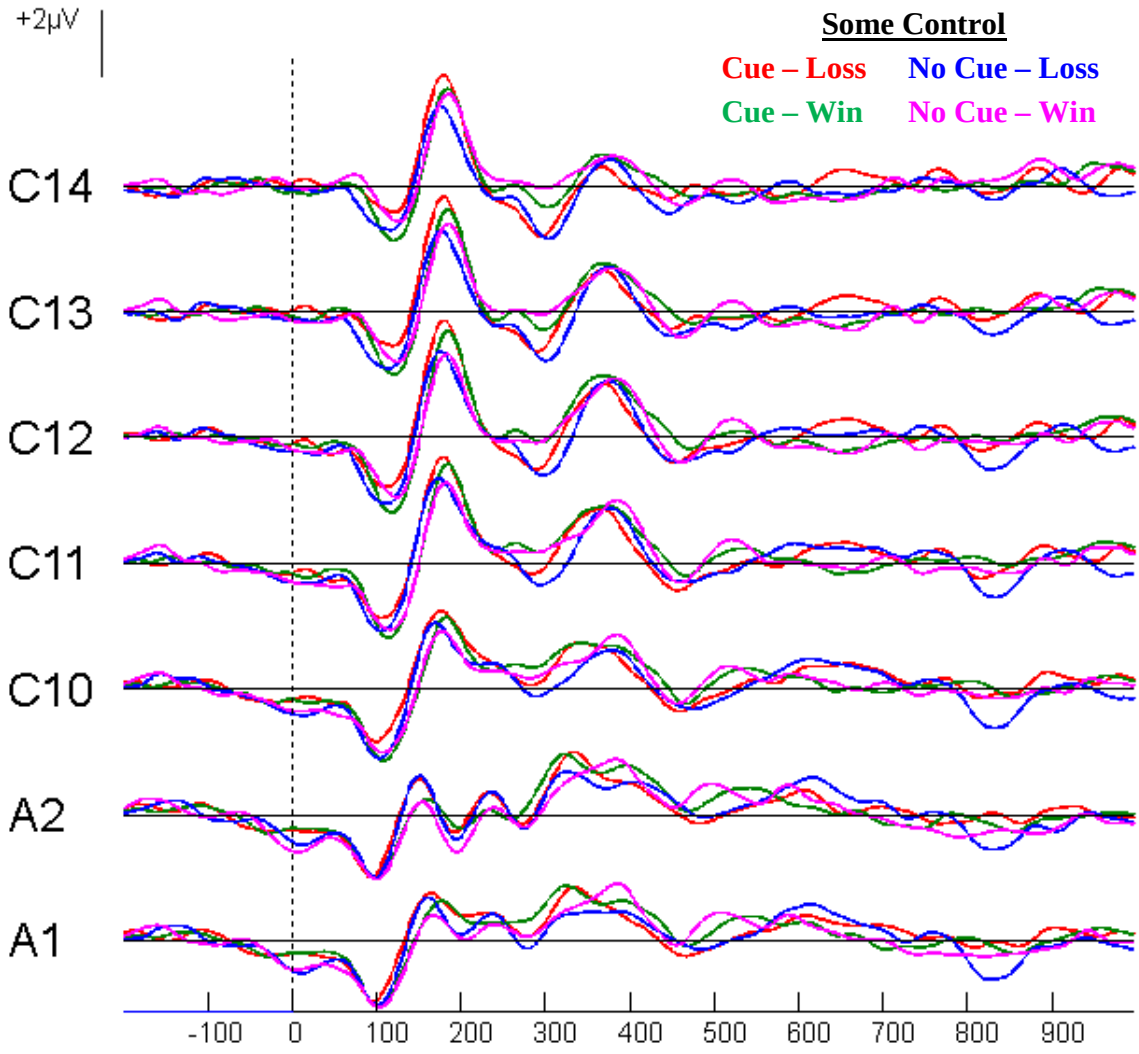


Figure 2.11. Averaged ERP waveforms for the two types of cues and two types of outcomes received in the Some Control versions of the task observed in Experiment 2

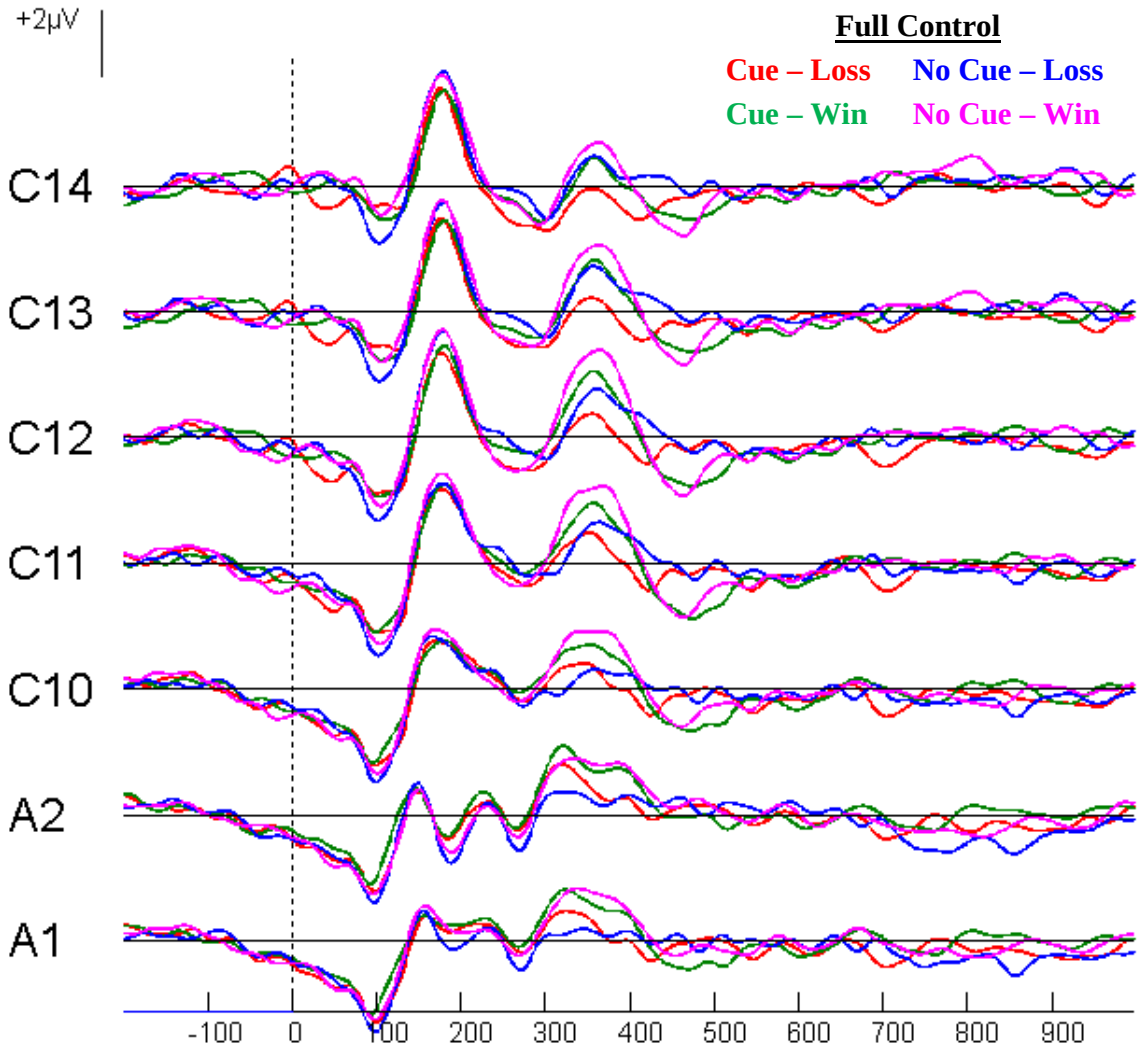


Figure 2.12. Averaged ERP waveforms for the two types of cues and two types of outcomes received in the Full Control versions of the task observed in Experiment 2.

APPEDIX 2.1

Informed Consent Form

Date:_____

Project Title: **The Role of Reward in Brain Electrical Responses**

Investigator	Investigator	Faculty Supervisor
Angela Dzyundzyak	**Diane Santesso**	**S.J. Segalowitz, Professor**
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ad03cr@brocku.ca	dlsantesso@yahoo.com	ssegalowitz@brocku.ca

INVITATION

You are invited to participate in a study that involves research. The purpose of this study is to measure brain activity while performing a computerized task as well as examine personal style and an individual's experiences relate to the brain patterns.

WHAT'S INVOLVED

As a participant, you will be asked to answer some questionnaires assessing activity preferences and experience in participating in gambling behaviors. Then a brainwave sensor net will be placed on your scalp. You will be asked to complete two tasks on the computer. In one of the tasks, you will be asked to estimate one second interval after disappearance of a cue. This task will have three types of trials (easy, normal and hard) and you will be given feedback on your performance (correct or incorrect) at the end of each trial. This task will be divided into 8 blocks, 5 minutes each. In the second task you will be asked to make a choice between four doors, each one of which can contain a reward. In some cases one, two or three doors can contain a reward. After your choice, you will be asked to estimate if you've won or lost on the trial. Once the response is made you will be shown if you've won or lost on the trial. This task will be divided into 12 blocks and the running total of your winnings will be shown at the end of each block. You will have an opportunity to take a break every 5 minutes, and a longer break between the two tasks. Once the computer tasks are finished, the sensors will be removed. Participation will take approximately 3 hours of your time.

POTENTIAL BENEFITS AND RISKS

Possible benefits of participation include the chance to see your brain activity on a computer screen, and ask questions of the researchers about EEG procedures and brain health. There are no known or anticipated risks associated with participation in this study.

CONFIDENTIALITY

All information you provide is considered confidential; your name will not be included or, in any other way, associated with the data collected in the study. Furthermore, because our interest is in the average responses of the entire group of participants, you will not be identified individually in any way in written reports of this research.

DATA STORAGE AND USE

Data collected during this study will be kept for 7 years after final publication of results and stored in a limited access area of the Brock Neuropsychology laboratory. Only researchers associated with the Brock Neuropsychology laboratory will have access to the data.

VOLUNTARY PARTICIPATION

Participation in this study is voluntary. If you wish, you may decline to answer any questions or participate in any component of the study. Further, you may decide to withdraw from this study at any time and may do so without any penalty or loss of benefits to which you are entitled. Monetary compensation will be based on the amount of money won at the end of the tasks.

PUBLICATION OF RESULTS

Results of this study may be published in professional journals and presented at conferences. Feedback about this study will be available through Angela Dzyundzyak (ad03cr@brocku.ca). As EEG data takes a long time to analyze, we do not anticipate full results of the study to be ready until September 2013.

CONTACT INFORMATION AND ETHICS CLEARANCE

If you have any questions about this study or require further information, please contact the Principal Investigator or the Faculty Supervisor using the contact information provided above. This study has been reviewed and received ethics clearance through the Research Ethics Board at Brock University (REB #11-224). If you have any comments or concerns about your rights as a research participant, please contact the Research Ethics Office at (905) 688-5550 Ext. 3035, reb@brocku.ca.

Thank you for your assistance in this project.

CONSENT FORM

I agree to participate in the study described above. I have made this decision based on the information I have read in the Information-Consent Letter. I have had the opportunity to receive any additional details I wanted about the study and understand that I may ask questions in the future. I understand that I may withdraw this consent at any time.

I am participating in this experiment for a monetary reward ($40 for participation and up to $25 depending on performance on the tasks). This experiment will not count toward research participation hours in a psychology course.

_____ _____

Signature of participant Signature of experimenter

Subject ID _____ Date: _____

7. How old are you?_____ What is your major/occupation?_____

8. Sex: M F What are your goals after the completion of your current degree? _____

9. Have you ever been diagnosed/experienced any neurological conditions (e.g. epilepsy, stroke, concussion etc)?

_____

10. Do you smoke cigarettes? Y N

If yes, approximately how many a day? _____

11. Have you experienced any recent stressor (e.g. death in the family, birth of a child, etc)?_____

12. For each of these activities, please decide which hand you normally use but checking the box. In each case, imagine that you are actually carrying out the activity before answering.

	1 Always Left	2 Usually Left	3 Either Hand	4 Usually Right	5 Always Right	6 Not Sure
1. Which hand do you use to write?	☐	☐	☐	☐	☐	☐
2. Which hand is used to throw a ball?	☐	☐	☐	☐	☐	☐
3. Which hand is used to draw?	☐	☐	☐	☐	☐	☐
4. Which hand is used to cut with a knife?	☐	☐	☐	☐	☐	☐
5. Which hand is used to hold a tennis racquet?	☐	☐	☐	☐	☐	☐
6. Hammer in a nail, which hand wields the hammer?	☐	☐	☐	☐	☐	☐
7. Which hand uses scissors?	☐	☐	☐	☐	☐	☐
8. Which hand strikes a match?	☐	☐	☐	☐	☐	☐
9. Thread a needle, which hand moves?	☐	☐	☐	☐	☐	☐
10. Which hand deals the cards?	☐	☐	☐	☐	☐	☐

Problem Gambling Severity Index

This self-assessment is based on the Canadian Problem Gambling Index. It will give you a good idea of whether you need to take corrective action.

Thinking about the last 12 months…

	Never	Sometimes	Most of the time	Almost always
1. Have you bet more than you could really afford to lose?	0	1	2	3
2. Still thinking about the last 12 months, have you needed to gamble with larger amounts of money to get the same feeling of excitement?	0	1	2	3
3. When you gambled, did you go back another day to try to win back the money you lost?	0	1	2	3
4. Have you borrowed money or sold anything to get money to gamble?	0	1	2	3
5. Have you felt that you might have a problem with gambling?	0	1	2	3
6. Has gambling caused you any health problems, including stress or anxiety?	0	1	2	3
7. Have people criticized your betting or told you that you had a gambling problem, regardless of whether or not you thought it was true?	0	1	2	3
8. Has your gambling caused any financial problems for you or your household?	0	1	2	3
9. Have you felt guilty about the way you gamble or what happens when you gamble?	0	1	2	3

Gambling Behaviour Questionnaire

PART A	***Please use THIS definition of gambling when you answer the rest of the questions on this survey.***

Gambling is betting / risking money on anything that is valuable to you (e.g, a CD, your bicycle, your computer, etc.) on an activity with an uncertain outcome.
The activities listed below are different types of gambling activities. How many times in the PAST YEAR have you done the following:

	NEVER IN THE PAST YEAR	1-5 TIMES IN THE PAST YEAR	6-11 TIMES A YEAR	ABOUT ONCE A MONTH	2-3 TIMES A MONTH	ABOUT ONCE A WEEK	2-6 TIMES A WEEK	DAILY
Played the lottery (i.e., 649, Super 7 or Pick 3)								
Played instant-win or scratch tickets								
Bought raffle tickets or fundraising tickets								
Played break open or pull tab tickets								
Played Sports Select/Pro-line								
Played bingo								
Bet on TV show outcomes (i.e. Survivor, Big Brother, The Bachelor, etc.)								
Played cards, board games with family or friends for money								
Played games of skill such as pool, golf, or darts for money								
Played arcade or video games for money								
Bet/gambled on the internet (i.e., poker, fantasy drafts, Facebook sports pools, games, etc.)								
Flipped coins / played dice games for money								
Played slot machines / poker or gambling machines / VLTs								
Bet on sports teams (e.g., hockey pools, football pools, any sports pools, etc.)								
Bet on horse races								
Played card or dice games at a casino								
Bet on sports with a bookie								
Bet money or objects on another game/activity that is not listed above (please specify): _____								

LOCUS OF CONTROL SCALE
DEVELOPED BY ROTTER (1989)

For each item, indicate which sentence you agree with by choosing either sentence (a) or sentence (b). Choose which item you agree with the most.

1.	A	Children get into trouble because their patents punish them too much.
	B	The trouble with most children nowadays is that their parents are too easy with them.
2.	A	Many of the unhappy things in people's lives are partly due to bad luck.
	B	People's misfortunes result from the mistakes they make.
3.	A	One of the major reasons why we have wars is because people don't take enough interest in politics.
	B	There will always be wars, no matter how hard people try to prevent them.
4.	A	In the long run people get the respect they deserve in this world
	B	Unfortunately, an individual's worth often passes unrecognized no matter how hard he tries
5.	A	The idea that teachers are unfair to students is nonsense.
	B	Most students don't realize the extent to which their grades are influenced by accidental happenings.
6.	A	Without the right breaks one cannot be an effective leader.
	B	Capable people who fail to become leaders hive not taken advantage of their opportunities.
7.	A	No matter how hard you try some people just don't like you.
	B	People who can't get others to like them don't understand how to get along with others.
8.	A	Heredity plays the major role in determining one's personality
	B	It is one's experiences in life which determine what they're like.
9.	A	I have often thought that what is going to happen will happen.
	B	Trusting to fate has never turned out as well for me as making a decision to take a definite course of action.
10.	A	In the case of the well-prepared student there is rarely if ever such a thing as an unfair test.
	B	Many times exam questions tend to be so unrelated to course work that studying in really useless.
11.	A	Becoming a success is a matter of hard work; luck has little or nothing to do with it.
	B	Getting a good job depends mainly on being in the right place at the right time.
12.	A	The average citizen can have an influence in government decisions.
	B	This world is run by the few people in power, and there is not much the little

		guy can do about it.
13.	A	When I make plans, I am almost certain that I can make them work.
	B	It is not always wise to plan too far ahead because many things turn out to- be a matter of good or bad fortune anyhow.
14.	A	There are certain people who are just no good.
	B	There is some good in everybody.
15.	A	In my case getting what I want has little or nothing to do with luck.
	B	Many times we might just as well decide what to do by flipping a coin.
16.	A	Who gets to be the boss often depends on who was lucky enough to be in the right place first.
	B	Getting people to do the right thing depends upon ability, luck has little or nothing to do with it.
17.	A	As far as world affairs are concerned, most of us are the victims of forces we can neither understand, nor control.
	B	By taking an active part in political and social affairs the people can control world events.
18.	A	Most people don't realize the extent to which their lives are controlled by accidental happenings.
	B	There really is no such thing as "luck."
19.	A	One should always be willing to admit mistakes.
	B	It is usually best to cover up one's mistakes.
20.	A	It is hard to know whether or not a person really likes you.
	B	How many friends you have depends upon how nice a person you are.
21.	A	In the long run the bad things that happen to us are balanced by the good ones.
	B	Most misfortunes are the result of lack of ability, ignorance, laziness, or all three.
22.	A	With enough effort we can wipe out political corruption.
	B	It is difficult for people to have much control over the things politicians do in office.
23.	A	Sometimes I can't understand how teachers arrive at the grades they give.
	B	There is a direct connection between how hard 1 study and the grades I get.
24.	A	A good leader expects people to decide for themselves what they should do.
	B	A good leader makes it clear to everybody what their jobs are.
25.	A	Many times 1 feel that I have little influence over the things that happen to me.
	B	It is impossible for me to believe that chance or luck plays an important role in my life.
26.	A	People are lonely because they don't try to be friendly.
	B	There's not much use in trying too hard to please people, if they like you, they like you.

27.	A	There is too much emphasis on athletics in high school.
	B	Team sports are an excellent way to build character.
28.	A	What happens to me is my own doing.
	B	Sometimes I feel that I don't have enough control over the direction my life is taking.
29.	A	Most of the time I can't understand why politicians behave the way they do.
	B	In the long run the people are responsible for bad government on a national as well as on a local level.

HEXACO-PI-R

Directions:
On the following pages you will find a series of statements about you. Please read each statement and decide how much you agree or disagree with that statement. Then write your response in the space next to the statement using the following scale:

Strongly disagree	Disagree	Neutral	Agree	Strongly Agree
1	2	3	4	5

Please answer every statement, even if you are not completely sure of your response.

1.	_____	I would be quite bored by a visit to an art gallery.
2.	_____	I plan ahead and organize things, to avoid scrambling at the last minute.
3.	_____	I rarely hold a grudge, even against people who have badly wronged me.
4.	_____	I feel reasonably satisfied with myself overall.
5.	_____	I would feel afraid if I had to travel in bad weather conditions.
6.	_____	I wouldn't use flattery to get a raise or promotion at work, even if I thought it would
7.	_____	I'm interested in learning about the history and politics of other countries.
8.	_____	I often push myself very hard when trying to achieve a goal.
9.	_____	People sometimes tell me that I am too critical of others.
10.	_____	I rarely express my opinions in group meetings.
11.	_____	I sometimes can't help worrying about little things.
12.	_____	If I knew that I could never get caught, I would be willing to steal a million dollars.
13.	_____	I would enjoy creating a work of art, such as a novel, a song, or a painting.
14.	_____	When working on something, I don't pay much attention to small details.
15.	_____	People sometimes tell me that I'm too stubborn.
16.	_____	I prefer jobs that involve active social interaction to those that involve working alone.
17.	_____	When I suffer from a painful experience, I need someone to make me feel comfortable.
18.	_____	Having a lot of money is not especially important to me.
19.	_____	I think that paying attention to radical ideas is a waste of time.
20.	_____	I make decisions based on the feeling of the moment rather than on careful thought.
21.	_____	People think of me as someone who has a quick temper.
22.	_____	On most days, I feel cheerful and optimistic.
23.	_____	I feel like crying when I see other people crying.

24. I think that I am entitled to more respect than the average person is.
25. If I had the opportunity, I would like to attend a classical music concert.
26. When working, I sometimes have difficulties due to being disorganized.
27. My attitude toward people who have treated me badly is “forgive and forget”.
28. I feel that I am an unpopular person.
29. When it comes to physical danger, I am very fearful.
30. If I want something from someone, I will laugh at that person's worst jokes.
31. I’ve never really enjoyed looking through an encyclopedia.
32. I do only the minimum amount of work needed to get by.
33. I tend to be lenient in judging other people.
34. In social situations, I’m usually the one who makes the first move.
35. I worry a lot less than most people do.
36. I would never accept a bribe, even if it were very large.
37. People have often told me that I have a good imagination.
38. I always try to be accurate in my work, even at the expense of time.
39. I am usually quite flexible in my opinions when people disagree with me.
40. The first thing that I always do in a new place is to make friends.
41. I can handle difficult situations without needing emotional support from anyone else.
42. I would get a lot of pleasure from owning expensive luxury goods.
43. I like people who have unconventional views.
44. I make a lot of mistakes because I don’t think before I act.
45. Most people tend to get angry more quickly than I do.
46. Most people are more upbeat and dynamic than I generally am.
47. I feel strong emotions when someone close to me is going away for a long time.
48. I want people to know that I am an important person of high status.
49. I don’t think of myself as the artistic or creative type.
50. People often call me a perfectionist.
51. Even when people make a lot of mistakes, I rarely say anything negative.
52. I sometimes feel that I am a worthless person.
53. Even in an emergency I wouldn’t feel like panicking.
54. I wouldn’t pretend to like someone just to get that person to do favors for me.
55. I find it boring to discuss philosophy.

56. _____ I prefer to do whatever comes to mind, rather than stick to a plan.
57. _____ When people tell me that I'm wrong, my first reaction is to argue with them.
58. _____ When I'm in a group of people, I'm often the one who speaks on behalf of the group.
59. _____ I remain unemotional even in situations where most people get very sentimental.
60. _____ I'd be tempted to use counterfeit money, if I were sure I could get away with it.

Doors task

Please answer the following questions regarding your experiences during the task using the scale provided.

Not at all (0)	**Rarely** (1)	**Occasionally** (2)	**Sometimes** (3)	**Frequently** (4)	**Usually** (5)

1. How often did you win on a **1-cue** trial?	0	1	2	3	4	5
2. How often did you win on a **2-cue** trial?	0	1	2	3	4	5
3. How often did you win on a **3-cue** trial?	0	1	2	3	4	5
4. Did you **feel** you could predict the outcome?	0	1	2	3	4	5
5. How **confident** were you in your predictions?	0	1	2	3	4	5
6. How **accurate** were you at predicting the outcome?	0	1	2	3	4	5
7. What was the likelihood of winning on a **1-cue** trial? (please answer in the space provided, e.g., 30%)						
8. What was the likelihood of winning on a **2-cue** trial? (please answer in the space provided, e.g., 30%)						
9. What was the likelihood of winning on a **3-cue** trial? (please answer in the space provided, e.g., 30%)						

10. Did you have **any strategy**? If yes, please explain below.

_____

_____

_____

11. Do you have any **other comments** about the task that we did not address? If yes, please use the space below to expand.

_____

_____

_____

_____

Time Estimation task

Please answer the following questions regarding your experiences during the tasks using the scale provided.

Not at all (0)	Rarely (1)	Occasionally (2)	Sometimes (3)	Frequently (4)	Usually (5)

1. Were the cues helpful?	0	1	2	3	4	5
2. Did you have a feeling of control over the outcome?	0	1	2	3	4	5
3. How often did you feel you would **win** on an **easy** cue?	0	1	2	3	4	5
4. How often did you feel you would **lose** on a **hard** trial?	0	1	2	3	4	5
5. How confident were you in your predictions?	0	1	2	3	4	5
6. How accurate were you at predicting the outcomes?	0	1	2	3	4	5
7. How hard did you try on an **easy** cue?	0	1	2	3	4	5
8. How hard did you try on a **hard** cue?	0	1	2	3	4	5
9. Was the feedback helpful?	0	1	2	3	4	5
10. Please estimate the likelihood of **winning** on an **easy** trial? (answer in the space provided e.g., 50% of the time)						
11. Please estimate the likelihood of **losing** on a **hard** trial? (answer in the space provided e.g., 50% of the time)						

12. Did you have **any strategy**? If yes, please explain below.

_____

_____

_____

13. Do you have any **other comments** about the task that we did not address? If yes, please use the space below to expand.

_____

_____

_____

_____

Feedback Form – Neuropsychology Lab -- Brock University

Title of Study: **The Role of Reward in Brain Electrical Responses**

Dear Participant,

Thank you for taking part in this study! Without the help of volunteers these types of studies could not be done.

As you are aware, this research study was conducted as collaboration between Brock University and University of Waterloo. The purpose of this study was to examine the effects of reward expectancy and perceived control over the outcome on brain wave responses, known as the event-related potential (ERP).

Previous research has shown that feedback related negativity (FRN), an ERP component observed after presentation of feedback, is sensitive to reward expectations, such that unexpected events (wins or losses) lead to a larger FRN amplitude. In this study, we tried to manipulate reward expectancy by either varying the probability of an outcome (e.g., 3 out of 4 doors lead to wins) or through instructions (e.g., easy trial, where most people win). Although these manipulations might have a similar effect on the behavior, both rely on different networks in the brain. Currently, the majority of research suggests that FRN can be modulated by stimulus-driven information (e.g., probability). We are predicting that the perception of higher probability of reward (i.e., just believing you are more likely to win), has a similar effect on the FRN. Demonstration of such an effect would suggest that FRN is a reflection of combination of both networks (stimulus and psychological state), rather than if a simple stimulus-response pattern.

In order to differentiate these influences, we want to compare the brain responses to the outcome in the two tasks. The ERPs obtained during the doors task will inform us how the brain responds to outcomes of different probabilities. In comparison, the time estimation task will provide information on the effect of instructions on the brain responses to expected vs. unexpected outcomes. It must be noted that in this task, the difficulty of the trials did not change with the type of cue. In both tasks the outcomes were predetermined and, thus, do not reflect your actual performance. This was necessary to ensure that we have enough trial of each type (e.g., win cue, win outcome) for analysis. Additionally, we had to ensure that the frequency of the outcomes in the time estimation task were equal across all cues, to eliminate potential influences of probability on the brain responses.

In addition to comparing the tasks, this study examined the role that individual differences play in reward prediction. The questionnaires that you have completed were designed to measure levels of various individual differences in gambling behaviors as well as personality traits such as sensation-seeking, impulsivity and optimistic bias. These data will later be used to examine the extent to which individual differences contribute/related to the processing of feedback information. As you are aware, all the data will be kept strictly confidential and thus during the scoring of the questionnaires you will not be identified in any way.

If you would like to learn more about the results of this study you could call Angela Dzyundzyak at the 905-688-5550, Ext. 3034, or through email (ad03cr@brocku.ca). It takes a lot of time to do the analyses though so the results are not likely to be ready before September 2013; however, if you are interested in the results feel free to leave your email and we will let you know when the results are available.

If you have any concerns or would like to find out more about gambling-related issues the Ontario Problem Gambling website is a good resource (http://www.problemgambling.ca). Additionally, Ontario Problem Gambling Helpline (24-hour on call service: 1-888-230-3505) offer counseling services for individuals with gambling problems.

Thank you again for taking part! Your help was very much appreciated.

If you have any issues you would like to discuss regarding your involvement in the study, you could call the Brock Research Ethics Board through the Research Office at 905-688-5550, Ext. 3035.

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APPENDIX 2.2

Doors Instructions[14]

"A cue indicating how many doors contain a prize will appear on the screen.
[A cue of X…means…]

1 - 1 door contains a prize.
2 - two doors contain a prize.
3 - 3 doors contain a prize.

Your job is to pick the door by pressing a button on the response pad.
The doors correspond to the button in the following order: A, B, C, D.
[Experimenter points to the buttons from left to right, such that response 1 = door A on the left]

Once you choice is made you will be asked "Do you think you will win on this trial?"
Press 1 for Yes and 4 for No. [Put Post-Its on the table with "Y" on participant's left and "N" on the right]
Start with a 6 trial practice."

Time Estimation Instructions[15]

"For this task you will be asked to estimate time.

A cue, will appear indicating that the trial will be easy or hard.
[The cue will be a green or a red square]

A GREEN square means the trial will be easy.
A RED square means the trial will be hard.

After the cue the screen will go blank.
Press 4 when you think that the screen has been blank for 1 second.
[So the cue will flash on the screen and when it has disappeared your time starts]

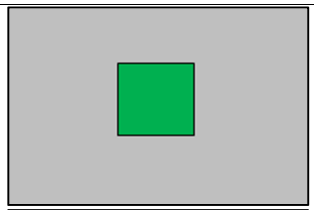
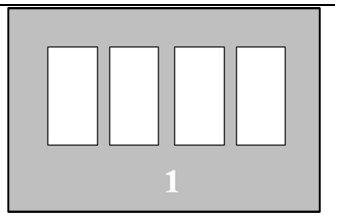
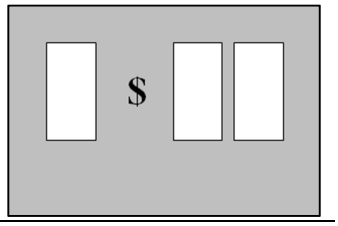
On EASY trials [or green square trials] you will win if you press 4 between 500 and 1500 ms.

On HARD trials [or red square trials] you will win only if you press 4 exactly at 1 sec.
[So the green trials are easier because there is a larger window for error. Most people tend to do well on the easy ones and not so well on the hard trials]
Start with a 6 trial practice"

*The last sentence varied slightly between participants to make it sound as a spontaneous comments rather than part of the script, but always contained information that others do well on easy trials and poorly on hard trials.

[14] Note: [ ] indicate instructions given verbally and not presented on the screen.

Study 2: Visual Angles

	Vertical	Horizontal	
Time Estimation			
Cue	5.06	5.06	
Win feedback	1.05	3.34	
Loss feedback	1.05	4.30	
Doors			
Cue	7.72	18.27	
Feedback	5.06	18.27	

Study 2: Average number of trials used for FRN analysis in each condition (after artifact rejection).

	Doors		**Time Estimation**	
	Win	Loss	Win	Loss
Expected	105	68	52	52
range:	74-152	11-125	36-59	39-60
Unexpected	41	80	51	51
range:	6-77	27-153	35-59	33-58

APPENDIX 2.3

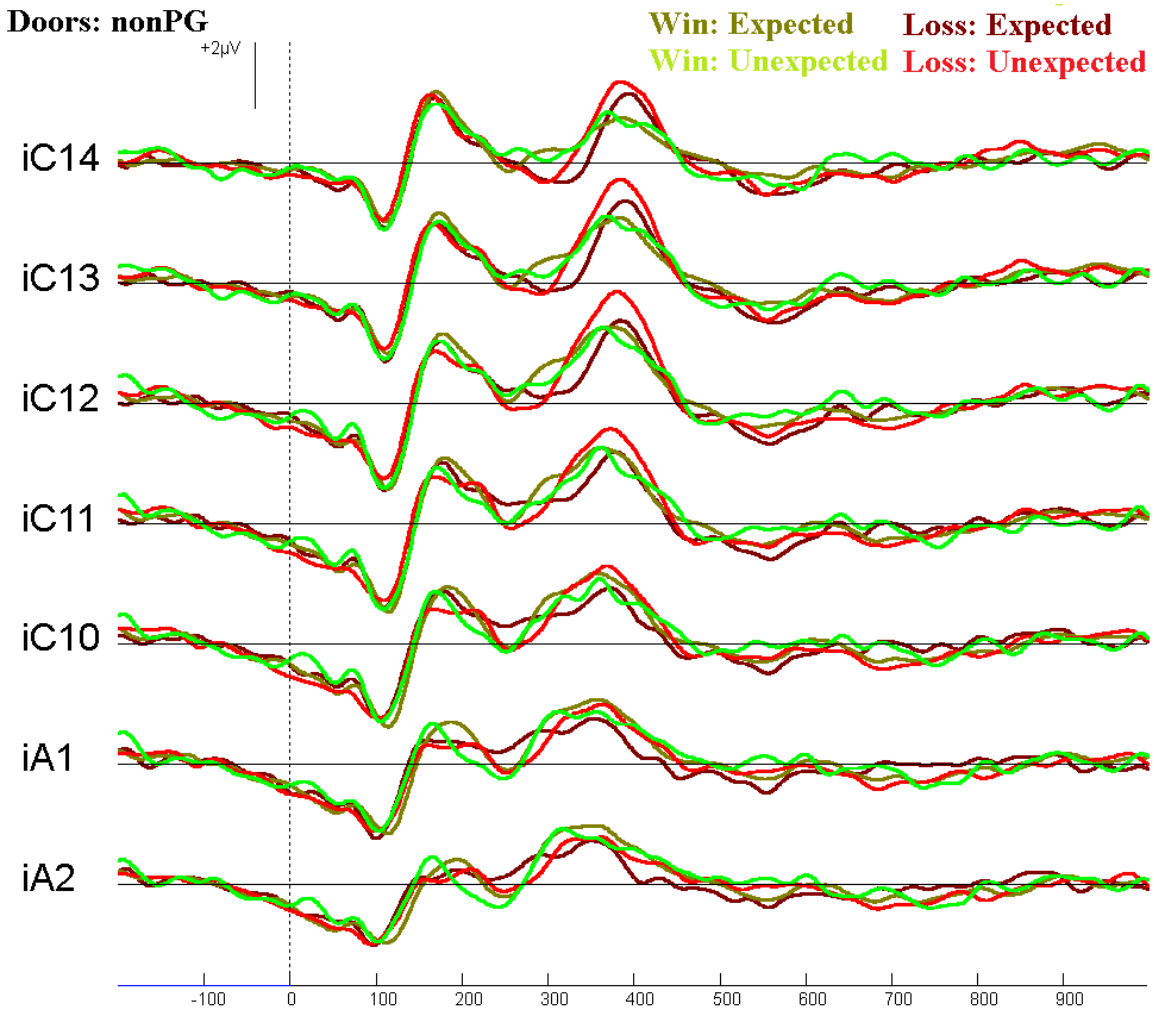


Figure 3.4. Average ERP waveforms elicited by the four types of feedback conditions in the Doors task (nPG group).

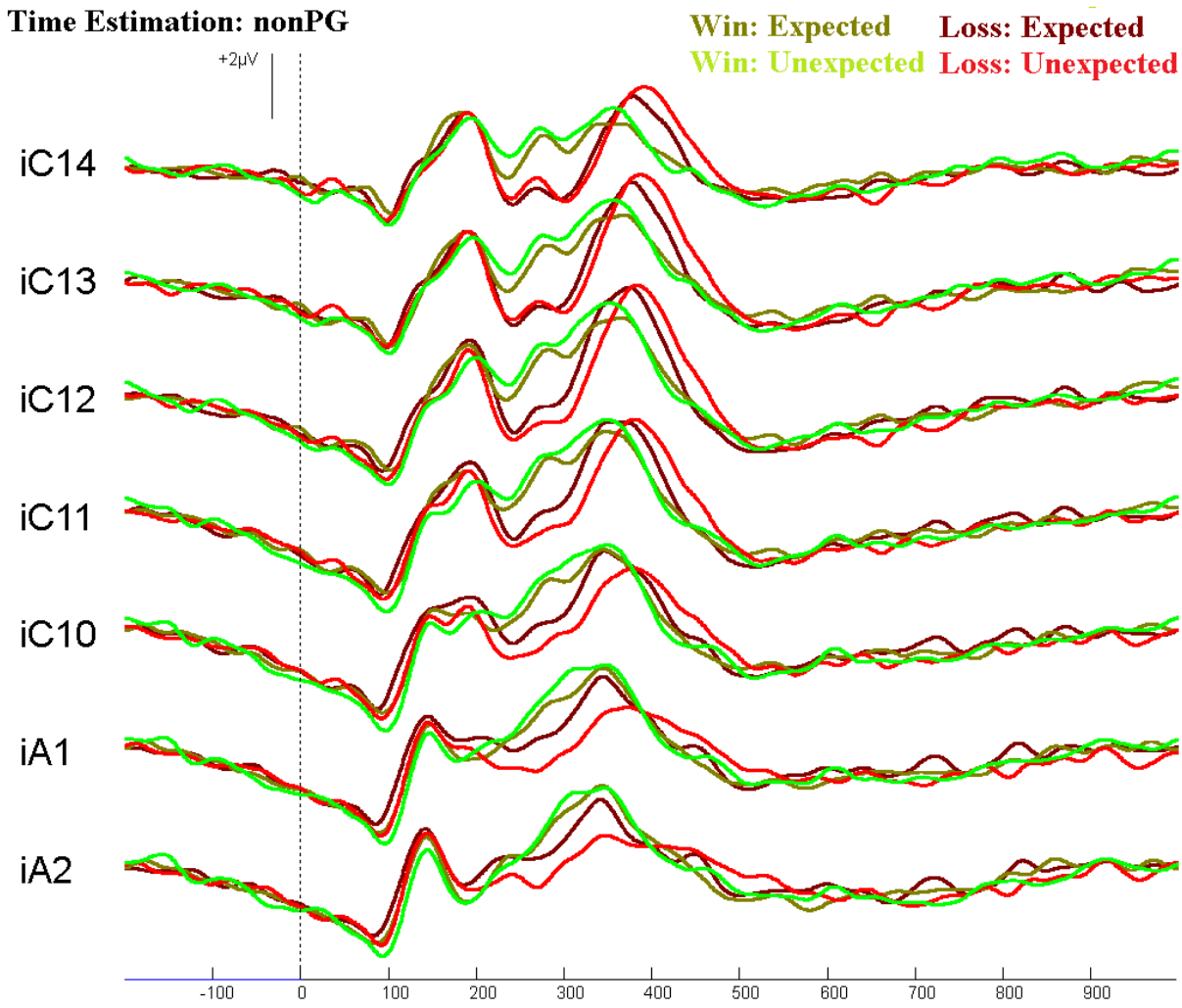


Figure 3.5. Average ERP waveforms elicited by the four types of feedback conditions in the Time Estimation task (nPG group).

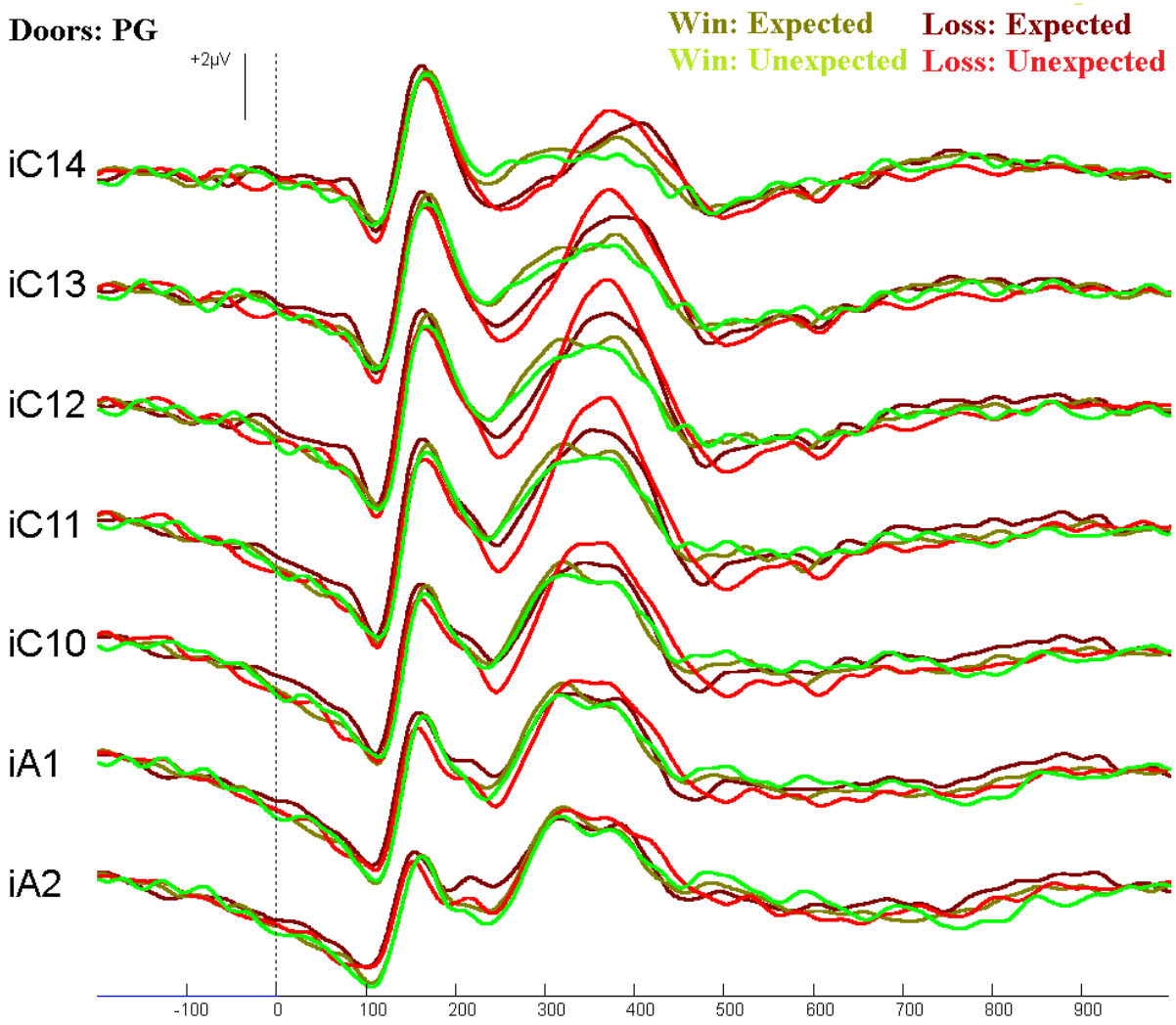


Figure 3.6. Average ERP waveforms elicited by the four types of feedback conditions in the Doors task (PG group).

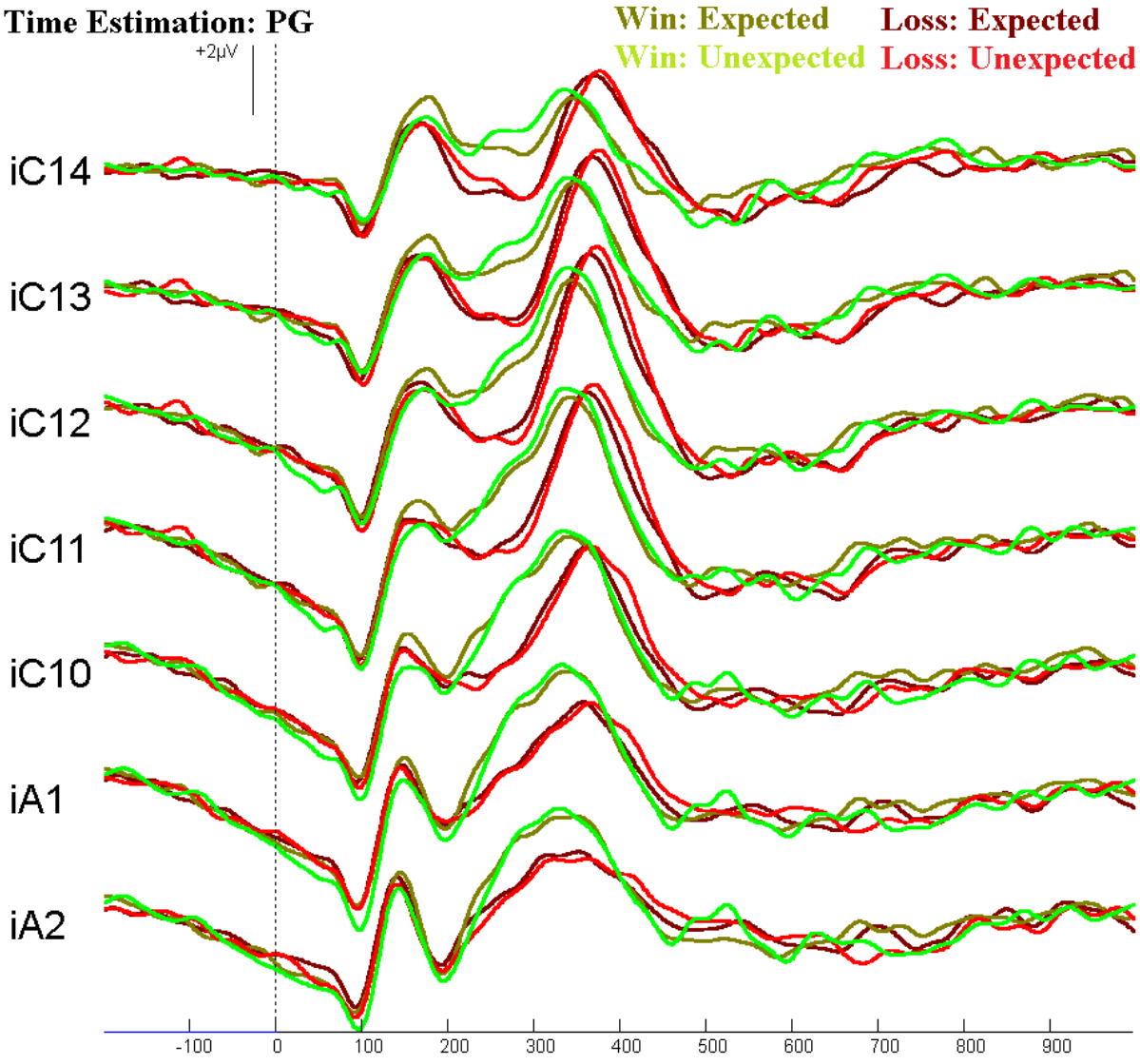


Figure 3.7. Average ERP waveforms elicited by the four types of feedback conditions in the Time Estimation task (PG group).